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11th-14th SEPTEMBER 1961

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THE ROYAL AERONAUTICAL SOCIETY

MAY 1961

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None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 MAY 1961 NUMBER 605

The President 1961-62

SIR ROBERT OWEN JONES was educated at Epworth College, Rhyl, at the Manchester College of Technology (combining with the course there a short apprenticeship in instrument making) and later at Cambridge, where he took the Mechanical Sciences Tripos. He then completed the post-graduate course in aeronautics at the Imperial College, specialising on research connected with high-compression aircraft engines.

Sir Owen joined the Royal Air Force in 1924 and alternated flying duty with technical duty until 1938. He served in Egypt and India as well as in England both as a pilot and as a technical officer and during this period also graduated from the R.A.F. Staff College at Andover. His technical duty included the command of station workshops on aircraft maintenance and overhaul, technical instruction of officers and airmen and from 1931-1934, he was at the Royal Aircraft Establishment, Farnborough on instrument design, in particular on the development and air-testing of the gyro-magnetic distant reading compass, later widely used in heavy aircraft of the Royal Air Force. His pilot duty during this pre-war period included over two years in command of No. 11 (Bomber) Squadron in India during which time he took part in the opening of the air reinforcement routes from the North West Frontier eastward to Singapore and westward to Cairo. For his part in this work he was awarded the Air Force Cross.

Immediately before the Second World War he was recalled from India to become the Air Ministry Overseer at Armstrong Whitworth Aircraft Ltd. and Armstrong Siddeley in Coventry, particularly to see the Whitley bomber efficiently into Service use.

From 1941 until 1943 he was a member of the British Air Commission in the U.S.A., and then returned to England as Deputy Controller of Research and Development at the Ministry of Aircraft Production, a post he held until 1946. Immediately after the war in Europe ended, he took part in the evaluation in Germany of the aeronautical research and development which had taken place there during the war.

From 1946-1947 he served with Technical Services (Plans) at the Air Ministry and was then appointed Air Officer Commanding No. 24 Group, Technical Training Command. In 1948 he spent a year as Senior Air Staff Officer, R.A.F. Reserve Command, and then returned as A.O.C. to No. 24 Group, which controlled much of the technical training of apprentices and airmen of the R.A.F.

Vandyk

AIR MARSHAL SIR OWEN JONES, K.B.E., C.B., A.F.C., B.A.(Cantab.), D.I.C., F.R.Ae.S., M.I.Mech.E., R.A.F.(retd.).

In 1952 he was appointed Controller of Engineering and Equipment at the Air Ministry, a post he held until he retired from the Royal Air Force in 1956. Since then he has been a Consultant and is also an independent member of certain Government Committees. He was President of the Institution of Mechanical Engineers in 1958.

Sir Owen joined the Society in 1947 and was elected a Fellow in 1950. He has served on Council since 1955 and was a Vice-President of the Society from 1957-1960. He received his knighthood in 1953.

Sir Owen takes office after the Annual General Meeting on 4th May 1961.

NOTICES

Whitsuntide Holiday

The Offices of the Society will be closed from Friday afternoon, 19th May until Tuesday, 23rd May 1961.

Anglo-American Aeronautical Conference, September 1961

The Eighth Anglo-American Aeronautical Conference will be held in London from 3rd to 14th September 1961. Full particulars will be published in the June JOURNAL **but enclosed with this Journal is an application form for enrolment.**

49th Wilbur Wright Memorial Lecture, 12th September 1961

The 49th Wilbur Wright Memorial Lecture will be delivered on 12th September 1961 during the Anglo-American Conference. The Lecturer will be Dr. Abe Silverstein, Director of Space Flight Programs, National Aeronautics and Space Administration, Washington.

Rotorcraft Section Garden Party

The Rotorcraft Section's Helicopter Rally and Garden Party will be held on Saturday, 17th June 1961. Mr. and Mrs. Charles Hughesdon have again generously offered the use of their beautiful grounds at Ripley, Surrey.

Attendance will be by invitation only.

Lecture Theatre Appeal

Donations are still welcomed as further items of equipment are continually being found necessary for the successful operation of the Lecture Theatre, as the result of the experience gained since the Opening Ceremony.

The final cost has yet to be ascertained but there is every hope that the Fund will prove sufficient to meet the total expenditure, including certain modifications now being carried out.

In the meantime the following contributions received since the publication of the previous list are gratefully acknowledged:—

Donations	£	s.	d.
Anonymous (3)	2	6	0
E. J. Brennan, Esq.	2	0	0
Brough Branch (additional)	39	3	0
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(with Income Tax at the present rate of 7s. 9d. in the £ these two covenants should produce £51 over the 7-year period).

The Grand Total has now reached £111,950 0s. 0d. (approx.).

An Interesting Relic

Recently while some of the effects of the late Queen Mary were being sorted before removal from the basement of Marlborough House it was discovered that among them was an old Blériot Propeller. Thanks to the help of Mr. Francis Watson, Assistant Surveyor of the Queen's Works of Art at the Wallace Collection, who has been supervising this work, the Society was asked if it would be interested in having this propeller. As a result of discussions which subsequently took place the Council have been informed by Brigadier Sir Norman Gwatkin, K.C.V.O., D.S.O., Controller, Lord Chamberlain's Office, St. James' Palace, that Her Majesty the Queen approves of the Society holding this propeller on permanent loan. The Council has asked Sir Norman Gwatkin to convey their grateful thanks to the Queen for this generous gesture.

One point of particular interest is that despite careful enquiries by Mr. Watson no information has come to light as to the origin of this propeller except the bare fact that it was specially designed and built by Lang Propellers Ltd. of Weybridge for the English Blériot Company and was for an 80 h.p. Gnôme engine. It is hoped that members may be able to supply the missing information as to how the propeller should have come into Queen Mary's possession.

Associate Fellowship Examination, June 1961

The Associate Fellowship Examination will be held on 13th, 14th, 15th and 16th June 1961. The time-table will be sent to all candidates entered for the examination.

Agricultural Aviation Group Annual General Meeting

The Second Annual General Meeting of the Agricultural Aviation Group will be held on Wednesday, 24th May 1961 at 7.30 p.m. at 4 Hamilton Place, London W.1.

Acknowledgments

The Council wishes to thank Mrs. Hilda Williams for presenting to the Society the log book of her brother, Wilfred Parke, and a copy of a pamphlet "Flying—Impressions and Notes" by Gustav Hamel. The last entry in Wilfred Parke's log book is for 10th December 1912—five days before he was killed.

The Council also wishes to thank M. W. Martin, Esq. (*Associate Fellow*) for the gift, on behalf of his father-in-law, of a copy of the Christmas number, 1918, of *The Wing*, the station magazine of R.A.F. Felixstowe. This copy is of particular interest as it contains a short history of the station, under the title "Seaplanes, Felixstowe" including a photograph of "The giant BABY with the BRISTOL BULLET aloft in which Flt. Lieut. Day performed his famous feat, waiting to take the water."

The Council is grateful also to Mrs. Muriel Balston, 9 Wilbraham Place, S.W.1 for a cutting book, some photographs and other aeronautical material, the property of her husband, the late R. M. Balston, Esq. (*Founder Member*).

Annual Report of the Council—April Journal

In the Annual Report of the Council, on p. 279 of the April JOURNAL, it was unfortunately incorrectly stated that no nominations for the Royal Aeronautical Society University Prize had been received from Queen Mary College in 1960. The final paragraph of this item in the Report *should* have read "There were no nominations for the prizes from Northampton College of Advanced Technology, London University or Glasgow University."

D. S. Woodward was nominated by Queen Mary College in 1960 and received a R.Ae.S. University Prize.

DIARY

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

24th May

AGRICULTURAL AVIATION GROUP—Annual General Meeting. **7.30 p.m.**

ASTRONAUTICS AND GUIDED FLIGHT SECTION

18th May

The Agena Satellite and the Discoverer Programme. R. Smelt. **6 p.m.**

GRADUATES' AND STUDENTS' SECTION

10th May

Aeroflot. G. A. Yarotski. **7.30 p.m.**

ROTORCRAFT SECTION

2nd June (Postponed from 7th April)

Development of Stabilising Equipment for Helicopters. P. D. MacMahon. **6 p.m.**

ELECTIONS

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Thomas Shelley Beddoes (*from Graduate*)
John Weston Chase
John Clarke
John Charles Firmin
Roderick Owen Gates
Denis Alec Morley Jackson
George Rowland Jefferson
Jagat Narain Kanwar
Joseph Mashman
Raymond Geoffrey Todd Munday
Gerard Talbot O'Brien (*from Graduate*)
Dilip Kumar Ray (*from Graduate*)
Brian Skidmore
Norman Compton Soper
Eric Raymond Taylor
Alampallam Vaidyanatha Viswanathan (*from Graduate*)
Sydney Wilson Wright

Associates

Dennis Frederick Cook
Leonard George Cooper
Douglas Jellicoe Mason Coxhead
Derrick Raymond Gatley
Bernard William James
George Albert Loake
William John McKeon
William Arthur George Marsh (*from Companion*)
Ronald Arthur Payne
Howard Anthony Perry
Edward Ernest Read
Walter Richardson
Leonard Norman Wilfred Starling
Charles William Stewart

Graduates

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Richard Hayes (*from Student*)
Peter Hewson (*from Student*)
Peter Barry Horsley (*from Student*)
John David Wright Hossack
David Edward Arthur Houghton
Alan Jackson
Norman Jackson
Henry Kinloch
John Walter Knight
Ajit Nanda Kumar
John Nokes
John Charles Stuart Prince (*from Student*)
Peter Leonard Ruthen (*from Student*)
Neil Thompson (*from Student*)
Peter John Walker (*from Student*)
John Grahame Dighton Walker
John Gurney Wilson
Robert Thomas Wrinch

Students

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Henry Faulks
Alan Leslie King
Charles Oliver O'Leary
Alan Painter
Tomas Fco. Capote Santiago
Colin Thomas Timms

Companions

John Black Morton Morrison
Noel Hamilton Forbes Unwin

Lecture Summaries

THE HELICOPTER, THE FIRST OF THE VTOL AIRCRAFT

RAOUL HAFNER

To be given on Friday 5th May 1961

A survey is made in retrospect and prospect of the field of VTOL aircraft. The helicopter and the new VTOL aircraft, although historically separated and differing in appearance, belong to the same family of VTOL aircraft. The dominant parameter in this family is the disc loading, giving the two fundamental types of actuator disc—open disc or rotor and buried disc or fan. Noise and vibration criteria are discussed. The rotor is subject to fundamental aerodynamic limitations. which give speed limits for the pure rotor as well as the rotor compounded with a fixed wing. Rotors are subject to scale effects which limit the economic size of helicopters. Engine requirements for helicopters are discussed. There are three basic types of helicopter. Their characteristics, their economics and their uses are examined. *To be published.*

DIRECT ELECTRICAL POWER GENERATION BY THERMAL AND CHEMICAL MEANS

PROFESSOR M. W. THRING

Given on 11th April

Electricity has been generated from fuel for many years by the steam cycle and is now being generated from nuclear fission by this cycle, but the overall efficiency of all cycles involving steam is limited by the upper temperature T_1 at which the bulk of the heat is absorbed.

T_1 is fixed by the need to pass heat through and act upon rigid metal walls and by the temperature pressure relation for the liquid water steam system. There are three possible groups of methods by which these limitations could be overcome. The first is the *fuel cells.* At present a great deal of work is going on, on low temperature fuel cells below 300°C and medium temperature fuel cells in the 600-800°C range. Work on fuel cells in the 1,200-1,500°C range and on gas phase fuel cells in the 2,000-3,000°C range could be of considerable interest. *Thermoelectric systems* involve either (1) the use of semi-conductors in the solid state as thermocouple systems with a series of heated hot junctions and cooled cold junctions, or (2) the thermionic emitter. The thermocouple system is limited primarily by conduction of heat through the solid from the hot junction to the cold junction, and the efficiency depends upon the parameter $z=\alpha^2\sigma/K$ where α is the thermoelectric power in volts per °K. K is the thermal conductivity in watts/cm. °K and σ is the specific conductivity in ohms/cm. The best values of z attainable at present limit the efficiency of this system to about 11 per cent. The other type of thermoelectric system is the thermionic system where one electrode is heated and the other one cooled, and the space between them is either evacuated or filled with caesium vapour at low pressure. This requires very high temperatures for the high temperature electrode, and while at present the overall thermal efficiency is limited, it might be of interest in combination with a semi-conductor thermocouple system. The third type of direct electric power generation is the *electromagnetic gas-braking or M.H.D.* in which a very high velocity stream of high temperature gases are passed through an alternating or direct current magnetic field, and slowed down so that part of their kinetic energy is converted into current flowing to electrodes at right angles to the flow and the magnetic field. Pilot plants for this system have been built and operated in America, but the essential difficulty is to obtain a sufficiently high gas conductivity after the gas has been cooled by the adiabatic expansion necessary to give the high velocity. Methods proposed for overcoming this difficulty are (1) the use of a striated system with alternate layers of high conductivity gas and comparatively low temperature working fluid. (2) The use of pulsating combustion to give combustion at effectively constant volume instead of constant pressure, and (3) a double shock wave system giving brief pulses of current in opposite directions, as the shock wave passes from one end to the other of an exploding system through a magnetic field in the centre. Some possible aeronautical applications of the third of these methods are considered. *It is hoped to publish this lecture.*

ON THE ORIGIN, STRUCTURE AND GROWTH OF VORTEX SEPARATIONS

E. C. MASKELL

Given on 25th April

The main part of the lecture was devoted to a discussion of some recent contributions to the study of the vortex separations which occur in slender body flows. In particular, consideration was given to current ideas on the nature of boundary layer separation in a three-dimensional flow; to recent theoretical and experimental work on the structure of a "conical" vortex core; and to current theoretical work on the parameters which govern the growth of the vortices in the initial "small vortex" regime of flow past sharp-edged conical bodies. The lecture concluded with a brief discussion of separated flows in general with, as its main theme, the importance of the phenomenon of "vortex breakdown."

News of Members

R. G. Baxter (*Associate Fellow*) formerly Stress Office Section Leader, de Havilland Propellers Ltd., London, is now Chief Stressman, Government Aircraft Factories, Fishermen's Bend, Melbourne.

G. I. M. Beere (*Graduate*) formerly Technical Assistant, Aerodynamics Department, D. Napier & Son Ltd., is now Engineer, Systems Department, English Electric Aviation Ltd., Guided Weapons Division, Luton.

F. E. Bisset (*Associate*) formerly Technical writer with Vickers-Armstrongs (Aircraft) Ltd., Weybridge, is now in the Experimental Department, Hawker Aircraft, Dunsfold.

W. R. Bryce (*Associate Fellow*) formerly Stress Engineer, Avro Aircraft Ltd., Malton, is now in the Computing Department of the de Havilland Aircraft Co. of Canada Ltd., Ontario.

J. T. Burr (*Associate Fellow*) formerly Mathematics Master, Wellington Grammar School, Shropshire, is now Project Engineer, Air Conditioning, de Havilland Aircraft Co. Ltd., Hatfield.

Wing Commander R. S. C. Cater (*Associate Fellow*) has been posted from the Air Ministry to the Staff of H.Q., Technical Training Command, Brampton.

J. Cohen (*Associate Fellow*) formerly with Apollo Project Office, N.A.S.A. Space Task Group, Virginia, is now at the N.A.S.A. Goddard Space Flight Center, Maryland.

Warrant Officer J. Crampton (*Associate Fellow*) formerly at H.Q., R.A.F. Germany, is now at H.Q., Fighter Command, Stanmore. (Correction to April Notices.)

Sqn. Ldr. A. W. Culmer (*Associate Fellow*) formerly Officer Commanding, Engineering Squadron, Khormaksar, Aden, is now on the Technical Staff, H.Q. Middle East (Aden) Command.

D. R. H. Dickinson (*Associate Fellow*) has been transferred within the British Aircraft Corporation from Vickers-Armstrongs (Aircraft) Ltd., to Chief Flight Test Engineer at English Electric Aviation Ltd., Warton.

Flt. Lt. D. E. Dormer (*Associate Fellow*), having completed the Advanced Weapons Course at the R.A.F. Technical College, has been posted to the Guided Weapons Department, Royal Aircraft Establishment.

R. S. Easby (*Associate Fellow*) formerly Sales Manager (Fixed Wing Aircraft) Bristol Aircraft Ltd., is now Director in Charge of the Tokyo Branch and Assistant Director to the Chairman of Sino-British (Hong Kong) Ltd.

W. J. Eggington (*Associate Fellow*) formerly Chief of Special Projects, Saunders-Roe Ltd., is now Head of Projects (Hovercraft), Vickers-Armstrongs (South Marston).

R. J. Evans (*Associate Fellow*) formerly Head of the Department of Engineering, Burnley Municipal College, is now Head of the Department of Mechanical Engineering, Wolverhampton and Staffordshire College of Technology.

J. E. Garton (*Associate*) formerly Engine Overhaul Superintendent, B.E.A., is now Manager, Methods Services (Engineering and Maintenance), B.O.A.C., Heathrow.

Sqn. Ldr. R. F. Gash (*Associate Fellow*) having completed the Staff College Course at Bracknell, has been posted to Wright Patterson Air Force Base, Ohio.

J. E. Griffiths (*Associate Fellow*) formerly with Teddington Aircraft Controls Ltd., is now Technical Director, Tiltman Langley Ltd., Redhill.

P. G. Hannam (*Associate*) has left the R.A.F., and is now a Technical Engineer in the Flight Research Department of Bristol Aircraft Ltd.

W. A. Hibbert (*Associate Fellow*) formerly Inspector-in-Charge A.I.D. at Blackburn Aircraft Ltd., is now at A. & A.E.E. Boscombe Down, responsible for the Engineering Assessment of Helicopters.

Group Captain L. Kelly (*Associate Fellow*), having retired from the R.A.F., is now lecturing in Applied Mathematics at the University of Queensland.

M. J. Manning (*Graduate*) formerly Stressman, English Electric Aviation Ltd., is now a Lecturer in Aircraft Structures at Harris College of Further Education, Preston.

Sqn. Ldr. A. H. C. Markey (*Associate*) having completed No. 50 Course at the R.A.F. Staff College, Bracknell, is now Technical Co.-Ord. at H.Q. Coastal Command, Northwood.

E. B. Millward (*Associate*) formerly A.I.D., Alfred Miles Ltd., Glos., is now with Dowty Group Ltd., Cheltenham.

W. Morse (*Associate Fellow*) formerly Managing Editor of *Metalworking Production*, is now a freelance technical writer, editorial consultant, press relations adviser and publicity and promotion consultant.

P. Myers (*Student*) fomerly Engineering Apprentice, de Havilland Aircraft Co. Ltd., is now a Wind Tunnel Engineer with the Company.

J. C. McVeigh (*Associate Fellow*) formerly Lecturer in Mechanical Engineering, Borough Polytechnic, has been appointed Principal Lecturer in Mechanical Engineering.

D. Nichols (*Student*) formerly Research and Development Engineer at Gloster Aircraft Co. Ltd., is now Flight Test Engineer with Handley Page Ltd.

W. J. P. Parnell (*Associate Fellow*) formerly Stress Engineer, de Havilland Aircraft Co., Airspeed Division, Christchurch, is now a Technical Engineer with Bristol Aircraft Ltd., in the Bournemouth Design Office.

J. Pickles (*Associate Fellow*) formerly with English Electric Aviation Ltd., is now Chief Draughtsman of Lancashire Aircraft Co. Ltd.

P. Robinson (*Associate Fellow*) formerly Patents Officer, M.O.A., has been appointed Assistant to the Patent Adviser, Defence Research Staff, Washington.

M. A. Siddiqui (*Associate*) formerly Research Engineer, Sperry Gyroscope Company, is now a Senior Aerodynamicist, de Havilland Aircraft Co. Ltd., Hatfield.

J. Tribe (*Graduate*) formerly in the Blue Streak Trials Group, de Havilland Aircraft Co. Ltd., is now a Flight Test Engineer, Convair (Astronautics) Division, General Dynamics Corporation at Cape Canaveral, Florida.

Lt. Cdr. W. J. Tuck (*Associate Fellow*) having retired from the Royal Navy is now Assistant Keeper, Science Museum, Kensington, in the Department of Aeronautics and Sailing Ships dealing with the aircraft propulsion collection.

J. Venn (*Associate Fellow*) formerly P.S.O. Head Analogue Computer Group, Sir W. G. Armstrong Whitworth, Baginton, is now Senior Engineer in charge of Trials, E.M.I. Electronics Ltd., Australian Division, Salisbury.

L. Walker (*Associate*) formerly Company Chief Inspector, Scottish Aviation Ltd., has been appointed Company Chief Inspector for The Plessey Group of Companies.

B. W. Weller (*Student*) formerly Aircraft Weights Engineer, Handley Page Ltd., Cricklewood, is now an Aircraft Draughtsman with Baynes Engineering Ltd. (Aircraft Design Consultants) Bournemouth.

Flt. Lt. F. J. Wild (*Graduate*) on completion of No. 14 T.O. Graduate Course, Henlow, has been appointed O.C. Aircraft Servicing Flight, R.A.F. Geikenkirchen.

M. C. Wilson (*Associate Fellow*) formerly Senior Lecturer, Department of Flight, the College of Aeronautics, is now in the Aerodynamics Department, Boeing Airplane Co., Transport Division, Renton.

Wing Cdr. P. C. Wright (*Associate Fellow*) has retired from the R.A.F. and joined the Weymouth Branch of G. Alexander and Partners Ltd., Design Engineers.

April Journal—Correction

In the Discussion on Mr. Wheatcroft's lecture, p. 232, April Journal, Mr. D. J. Lambert (*Associate Fellow*) was incorrectly described as Senior Designer (Civil Aircraft), Vickers-Armstrongs (Aircraft) Ltd. He is, of course, Assistant General Manager (Development), Vickers-Armstrongs (Aircraft) Ltd.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 MAY 1961 NUMBER 605

The Fourteenth Louis Blériot Lecture

The Development of Short Range Air Transport Through The Use of V/STOL Aircraft

by

HENRI ZIEGLER

(General Manager, S. A. Louis Breguet)

The Fourteenth Louis Blériot Lecture "The Development of Short Range Air Transport through the use of V/STOL Aircraft," by General Henri Ziegler, General Manager, S. A. Louis Breguet, was given before a distinguished audience which included a number of visitors from France, on 23rd March 1961 in the Society's Lecture Theatre.

The President, Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., presided at the meeting. Before the formal proceedings the names of 17 members elected to Fellowship of the Society since December 1960 were read by the Secretary. (These names were published in the January, February and March JOURNALS—Ed.)

After congratulating the new Fellows, Dr. Moult said that this was one of those great occasions of the Society when they united with their friends from France to revere the memory of Louis Blériot, the first aviator to cross the Channel. This was on the 25th July 1909; since then, they would agree, great things had happened in the field of aeronautics.

The series of Blériot Lectures was inaugurated in Paris in 1948 between the Association Française des Ingénieurs et Téchniciens de l'Aéronautique (A.F.I.T.A.), and the Royal Aeronautical Society. The first Lecture had been given by Air Commodore F. R. Banks, and since then there had been an annual reunion alternately in London and in Paris, with distinguished Lecturers on both sides.

This was the fourteenth such reunion and they had with them again many of their friends from across the Channel including, he was delighted to see, a number of previous Lecturers, whom they were very pleased to welcome and to join with them in celebrating this great event.

They were disappointed that Madame Blériot had not been able on this occasion to make the journey from Monte Carlo. Unfortunately her doctor had advised against her travelling but, on their behalf, the following message had been sent to her that afternoon:—

The President, Council and Members of the Royal Aeronautical Society with their distinguished French guests attending the 14th Louis Blériot Lecture in London send to you Madame their kind thoughts and greetings on this occasion. In sending these greetings they look forward to meeting you on the occasion of the 15th Louis Blériot Lecture.

The following reply had been received:—

Reçois magnifiques roses tres touchée amiable attention du President et du Conseil des Membres de la Royal Aeronautical Society les prie d'accepter ses plus vifs remerciements avec l'expression de tout sa gratitude et des régrets de son éloignement—Mme. Louis Blériot.

It was now his great pleasure to introduce General Henri Ziegler. General Ziegler had had a most distinguished career, covering many aspects of aviation. He qualified as an Engineer from L'École Superieure de l'Aéronautique, became a Test Pilot and accumulated some 3,000 hours of flying on aircraft, including flying boats. He held a number of posts in the French Air Ministry and at the Flying Test Centre, of which he became Assistant Director. At the outbreak of war, in 1939, General Ziegler went to the United States as Chief Assistant with the Purchasing Mission for the French Ministry. He returned to Europe in 1941 and took an active part in the Resistance Movement until 1944, when under the name of Colonel Vernon, he assumed the post of Chief of Staff of the Free French Forces of the Interior, responsible to General Koenig in London. On the liberation of Paris he was appointed Military Governor of the city and in April 1945 led a delegation to the U.S.A. and Great Britain to resume technical and industrial aviation contacts. In 1946 he joined Air France, becoming General Manager. For a short period he returned to the French Civil Service in 1954 and joined his present firm, La Société des Ateliers D'Aviation, Louis Breguet, in 1956. Besides his wide aviation interests, General Ziegler was deeply concerned with the production and utilisation of nuclear energy and was, in fact, Vice-President of the Forum Atomique European—in brief, "FORATOM."

General Ziegler had been richly and deservedly decorated with many honours in his own country and elsewhere; he was a Commander of the Legion d'Honneur, held the Crôis de Guerre with three Palms, the "Rosette" of the Resistance and was a Commander of the Order of the British Empire, to mention only some of his honours. Thus, they had as their lecturer a very great man and he had much pleasure and anticipation in asking him to present the Fourteenth Louis Blériot Lecture.

Introduction

During the past two years, the new jet-propelled air liners have opened a new era in the field of air transport. This trend has been most evident in trans-continental or inter-continental flights for which the growth has been much faster than initially anticipated.

It is expected that a new revolution is going to occur in another field, that of short range air transport, where the changes will probably be as spectacular as in the long range services. This is mostly due to the latest technological developments of short—or even vertical—take-off and landing aircraft.

What are the conditions for those developments?

How can the V/STOL aircraft meet the requirements for the air transport of tomorrow?

These are the questions I would like to discuss.

More than ten years ago, Sir Frederick Handley Page gave in France the Third Louis Blériot Lecture in which he expressed his views on a safer aircraft and more economical ground equipment.*

I am grateful and honoured to be in a position today to comment on the latest progress in the field of short take-off and landing aircraft. I think that the Louis Blériot Lectures devoted to Anglo-French aeronautical scientific co-operation are an excellent opportunity to discuss techniques in which our mutual achievements are of some value.

PART I
CRITERIA FOR THE DEVELOPMENT OF SHORT RANGE AIR TRANSPORT

At the present time, 70 per cent of the passengers crossing the North Atlantic, between Europe and America, travel by air. The constant development of the traffic in this area is a great encouragement to the air lines and to the Industry. There is, however, no hope of seeing an explosive development in that field, but a steady rise, as shown on Fig. 1.

The expansion of the traffic will be due mostly to the normal rate of development of the number of passengers, but there remains little to be diverted from ships.

The picture is entirely different in the case of short range air transport, where the aircraft is carrying a very small percentage of the total traffic. A little change in that percentage might mean a drastic revolution in domestic airlines, increasing their traffic substantially. As an illustration of this, Fig. 2 shows the distribution of passenger traffic in the United Kingdom. It is seen that air transport accounts for 0·4 per cent of the public transportation, and 0·2 per cent of the total. It is obvious that a little change in this distribution could entail an enormous development of short haul air transport.

A different situation is shown from a consideration of similar statistics on passenger transportation in the United States (Fig. 3). From this it appears that air transport already accounts for 47·5 per cent of the total public transport, but only 4 per cent of total transport.

The difference as compared with European Countries, such as the United Kingdom, stems from the fact that the average distances are some ten times greater in the United States. The average traffic is already long range and has followed a development parallel to that of trans-Atlantic services. It is obvious that there remain many potentialities for short haul air transport when the appropriate material becomes available.

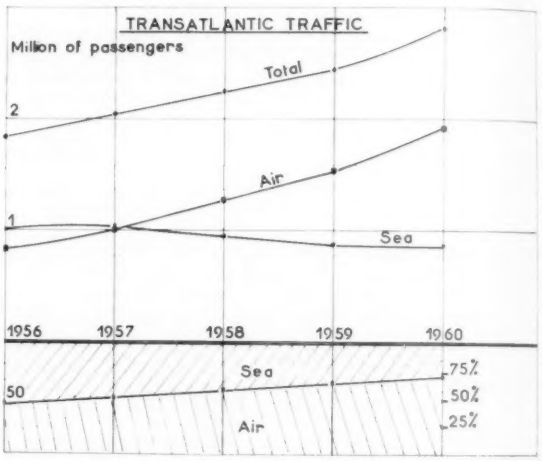


FIGURE 1. Passenger traffic over the North Atlantic routes.

Such statistics are only quoted as examples. They demonstrate, however, that air transport has an enormous field for expansion; but also that the struggle is severe. The aircraft has to be well adapted to its task to compete successfully with surface transport.

In this competition, the aircraft will have a better position in the next few years if it develops to achieve certain purposes which are not always easy to reconcile.

Those criteria, of paramount importance, might be listed as follows:

(*i*) Speed.
(*ii*) Flexibility in operation.
(*iii*) Reliability in service.
(*iv*) Safety.
(*v*) Economy.

	1951	*1959*	*Per cent increase*
Rail	24·3	25·5	+ 5%
Road	51·3	45·3	− 12%
Air	0·1	0·3	+200%
Total public	75·7	71·1	− 6%
Total personal	33·3	67·4	+102%
Total	109·0	138·5	+ 27%

FIGURE 2. Inland travel, United Kingdom (in 100 million passenger miles). (*Modern Transport*, 17th December 1960.)

	1955	*1959*	*Per cent increase*
Rail	231	176	−24%
Road	166	148	−11%
Air	199	294	+48%
Total public	596	618	+ 2%
Total personal	5860	6700	+14%
Total	6456	7318	+13%

FIGURE 3. Inland travel, U.S.A. (in 100 million passenger miles). (Reference I.T.A. 44, 5th December 1960.)

*Towards Slower and Safer Flying. Improved Take-off and Landing and Cheaper Airports. Sir Frederick Handley Page. Third Louis Blériot Lecture. *Journal of the Royal Aeronautical Society*, December 1950.

(i) Speed

Speed is certainly the main thing that the airlines have to sell. But this performance must necessarily be consistent with the overall organisation of traffic, taking into account the time spent on the ground, either in transportation from the city to the airport, or in warm-up, taxying and so on.

The relative importance of the dead time grows rapidly when the flight is short or interrupted by intermediate stops.

It is obvious that the possibility of using airfields located in the closest possible vicinity to the downtown areas is, if not vital, at least extremely favourable. This can be achieved under two conditions: that the aircraft uses a short runway, since it is usually impossible to find large available fields near the centres of cities; that the aircraft takes off and lands steeply in order to clear obstructions and also to avoid flying at low altitudes over inhabited areas. The noise level must be taken into account for this type of service, making sometimes unrealistic, technical solutions otherwise very attractive.

A very simple calculation has been made, based on a 250 statute miles stage length, assuming one hour transit time between city terminal and aircraft. To this time are to be added some 15 minutes for taxying.

From Fig. 4 it can be concluded that an aircraft flying at 200 kts. (230 m.p.h.) will save, on the overall terminal to terminal time, some 25 per cent compared with the time required by an aircraft flying at 100 kts. (115 m.p.h.) If the speed is increased by 100 kts. increments, it appears that the savings become 10 per cent (300 kts.), 6 per cent (400 kts.) and 4 per cent (500 kts.) respectively, in city terminal to city terminal time.

Speeds over 400 kts. (460 m.p.h.), which necessitate additional sophistication of the aeroplane, bring an almost negligible improvement, unless the type of service is completely re-organised in order to reduce the fixed ground time; this is not usually easy or economical to achieve, except with the V/STOL aircraft.

Another approach to the determination of the optimum speed is the consideration of head-winds. It appears, from the same Fig. 4, that if the aircraft is flying against a very common 20 kts. (23 m.p.h.) head-wind, it will be delayed by more than 25 minutes if it flies at 100 kts. (115 m.p.h.); by six minutes if it flies at 200 kts. (230 m.p.h.) and by less than two minutes if it is a 400 kts. (460 m.p.h.) air liner.

It would certainly be unpleasant for air services to have their timetables depending on the wind speed; helicopter services are affected in this way. It is necessary therefore to specify a speed high enough to ensure that the departure and arrival hours are almost independent of wind conditions. This requires speeds of over 200 kts. (230 m.p.h.)

Finally, it can be concluded that, for practical reasons, the speed of the short range aircraft must be above 200 kts. (230 m.p.h.) to allow fast and reliable service and yet must not be too high if it is to avoid penalising the airframe—and the economy—by the unavoidable complications involved in high speed flight.

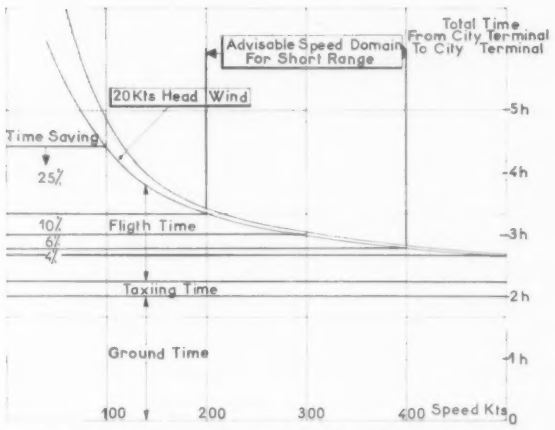


FIGURE 4. Effect of aircraft speed and head-wind on a 250 statute mile stage.

(ii) Flexibility of Operation

The operation on a somewhat extensive scale of short haul traffic requires the establishment of an overall network broken down into a large number of loading points in order to ensure the appropriate service. Surveys recently conducted have demonstrated that a short range domestic airline can serve communities within 60 statute miles radius around each airfield. This figure, actually, must be reduced if a convenient railway station is available in the vicinity. Thus a large number of intermediate stops are necessary for the type of service expected from the airlines. This extension of the number of small airfields for intermediate stops will be possible only if the required ground facilities are kept to a minimum and are as simple and as inexpensive as possible.

In the European Countries, there exists a large number of landing grounds for light aeroplanes which could be opened to commercial traffic requiring grass strips of some 2,000 ft. only.

For example, in France there are only some ten major airports available for normal scheduled trans-oceanic or trans-continental flights such as those operated by the Boeing 707 or DC-8. There are some twenty

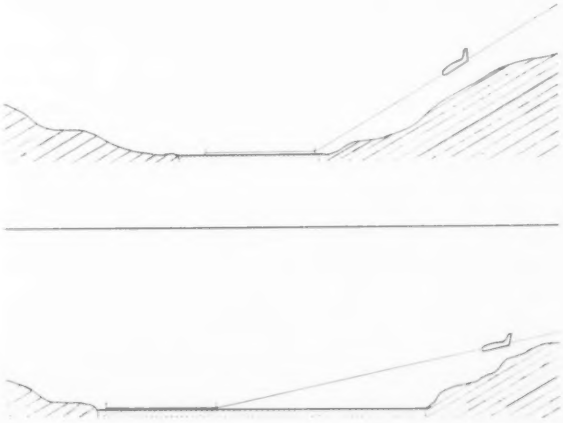


FIGURE 5. Use of aircraft in mountainous areas.

additional airports large enough for the Viscount class aeroplanes, but there are *more than 400 airfields* able to cope with the V/STOL transports of tomorrow.

In another area of application, the V/STOL transport can serve islands where it is not possible to build large runways, because of the available space, while air service is a first necessity and a public service. This approach could solve the traffic problems of Northern Scotland or of the Islands in the Pacific.

Finally, the V/STOL transport can open to air traffic many new areas in the mountains. I will develop later the importance of steep flight paths from a safety point of view, and their importance from the noise point of view in suburban areas has already been mentioned. But it should be emphasised that a slow flying aeroplane, requiring a small runway, is still restricted in operation if its approach angle is very flat (*see* Fig. 5). This point is of paramount importance in evaluating the various technical approaches to the short field type of operation.

In conclusion, the STOL capability, and eventually the hovering capability, seem to be essential to ensure proper flexibility of operation.

(*iii*) *Reliability of Service*

A satisfactory regularity is certainly one of the most essential features for a successful short distance service. In that respect, the conventional means are much more reliable, railways and, to a somewhat smaller extent, the highways being less sensitive to meteorological conditions than the air services. For instance, at Orly in 1959, 360 flights had to be re-routed to alternate airports, more than 90 per cent because of bad visibility during the winter season. In spite of many improvements in that field, and some spectacular new developments, the problem is being complicated by the constant increase of approach speeds. The cost of the necessary installations —on the ground as well as airborne—is following a parallel growth.

The procedure of approach in landing in bad—or zero—visibility conditions is to follow a flight path, predefined by radio or optical aids. The aircraft must not travel too far away from this path without the hazard of collision with the ground (*see* Fig. 6). Between the time when the pilot detects an error and the time when the aircraft is back again on the correct path, there is a certain time lag which is the total of the instrument observation time, pilot's time constant, time to manoeuvre and aircraft response. Most of this lag cannot be reduced so the distance travelled during correcting manoeuvres and, therefore, the practical operational minima are inversely proportional to the speed.

In addition, for a given rate of descent (which can be determined by the landing gear and aircraft structural strength when an impact occurs without flare) a low speed permits a much steeper angle of descent. It is seen that the increase of this angle is a very favourable factor because it avoids collisions with the ground. In addition, it makes the problem of landing aids somewhat easier since the aircraft is approaching far from the ground, so avoiding the difficult ground interferences which reduce the accuracy of conventional aids.

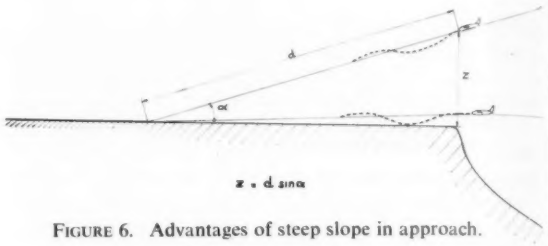


FIGURE 6. Advantages of steep slope in approach.

Ultimately, it might be expected that vertical landing could be achieved by very simple systems, such as associating a radio marker to a very accurate radio altimeter. Such altimeters have recently been developed giving the altitude with an error of less than one ft. Without going into detail on solutions presently being developed, it appears that reliability of operation can be achieved with simple means in view of the available technological development.

(*iv*) *Safety*

The number of casualties per mile travelled is already several times less on aircraft than on motorcars. The safety regulations developed recently have certainly achieved a satisfactory level in that field. In particular, the requirements in case of incident or failure of a vital part have led to the "fail-safe" concept in which those parts are duplicated, so largely increasing the safety level.

But, in developing short range traffic, air transport intends to divert passengers from other means of transportation and one of the main issues in selecting this type of transport is safety. In addition, a high percentage of the flying hours of the short range transport is over cities or suburban areas, so that accidents usually involve more casualities, as was unfortunately recently demonstrated in an accident in Munich.

(*v*) *Economy*

This factor is certainly the key to the existence of short range air travel, which will not develop so long as the cost of an air ticket is substantially higher than that of railways or buses. I think, however, that if a really economical aircraft can be developed it will not only take some of the customers from other forms of transport, but will also take an important part in the growth of the travelling public. The main reasons for not travelling are usually the time spent and the cost. I am quite confident that short range air transport equipped with the proper vehicles will be able to overcome both.

In order to give a schematic evaluation of the cost of various types of aircraft, I have tried to make a synthesis of the various operating cost evaluation methods proposed by a number of specialists. For an aircraft weighing between 30,000 and 50,000 lb., the cost in decimal pence per seat-mile can be approximated by the formula shown in Fig. 7. It can be stated as a first approximation that the cost of the airframe is essentially determined by the cost of the fuselage with all the necessary equipment and furnishings specified to fulfil the mission properly. Changes in wing area have a smaller effect on the overall cost.

$$240\times\frac{1\cdot2}{NV_b}\left[\frac{0\cdot142}{1000}C_A+\frac{0\cdot240}{1000}C_E+15+0\cdot02ne+0\cdot06N\right]$$
$$+240\times\frac{1\cdot2}{N.D}\left[C_F+20+0\cdot07N\right]$$

Where:

N	is the number of passengers
V_b	the block speed in m.p.h.
D	the stage length in statute miles
C_A	the cost of the airframe in £
C_E	the cost of power plants and ancillaries in £
ne	the number of engines
C_F	the cost of the fuel consumed for the stage D in £

FIGURE 7.

This is not so for the cost of the power plants which naturally covers not only engines and propellers, if any, but also auxiliary systems such as power shafts, B.L.C. pipings, ducts for propeller, and so on. With the power plants are included secondary devices such as those required for tilting engines, and also the special stabilisation devices used for pilot's aids. Those devices appear to have about the same maintenance and overhaul relative cost as the engines. In this way are shown the importance of and the effect on the operating cost of particular devices required to achieve the low speed flight necessary for short field operation.

To proceed in that study, it is necessary to examine, in view of the foregoing criteria, conditions for a satisfactory compromise and a technically sound solution.

PART II

TRAFFIC POTENTIAL OF THE VTOL/STOL TRANSPORTS

In order to achieve high speed ratios, that is to say high cruising speeds in combination with the very low approach speed necessary to utilise small airfields, many research programmes have been aimed towards the improvement of existing configurations. This approach has lead to a number of flying vehicles called "STOL" or "VTOL," depending on their capability to hover. I believe that, due to the flexibility of operation, the next generation of short range transport aircraft will be found among those developments.

Improvements to the Helicopter Configuration

Historically, the first VTOL vehicle was the helicopter and I would remind you that the first helicopter ever to fly was designed by Louis Breguet in 1907. Improvement to this type of machine was the first obvious approach. It appears that your engineers in the United Kingdom have achieved outstanding results with the concept of the compound helicopter as, for instance, the "Rotodyne."

I do not intend to comment on this approach which was excellently analysed in the Seventh Louis Blériot lecture by Mr. R. Hafner. I will restrict myself to the discussion of the improvements to fixed-wing aeroplanes which are another approach to the same problem.

VTOL and STOL Aircraft

The solutions considered to achieve with fixed-wing aeroplanes short or vertical take-off and landing capabilities are manifold, but all of them are based on an increase of lift.

Categories	*Utilisation of the power plant for lift augmentation*
Low wing-loading aircraft	nil
Boundary-layer-control aircraft	Indirect by bleeding compressed air
Convertible aircraft	Direct from the main power plant
Lift jet engine aircraft	Direct from secondary power plant

FIGURE 8.

In order to establish a classification, I have considered the way in which the installed power plant takes part in the lift augmentation and Fig. 8 lists the various categories. In all these categories, I will refer to only a few machines selected from among the most successful ones and restrict the list to aircraft actually flight tested. In addition, I will indicate briefly how, in our opinion, those concepts could be adapted to the realisation of a short range, medium size transport aircraft. As a basis for the calculation, I have assumed a type of service which appears to be of reasonable ambition—a transport of 50 tourist-class passengers operating 250 statute miles and 500 statute miles, the proper reserves being added to this range.

FIGURE 9. Dornier DO.27.

FIGURE 10. Grumman Mohawk.

Wing-loading, in lb./ft.²	39		31		26	
Empty weight, fully equipped, in lb.	24,300		26,100		28,100	
Maximum take-off weight, in lb.	39,400		41,800		44,500	
TOTAL POWER IN H.P.	3,780		4,160		4,610	
C_A Cost of airframe, in £	175,000		182,000		190,000	
C_E Cost of power plant, in £	57,000		62,000		68,000	
TOTAL COST OF AIRCRAFT, IN £	232,000		244,000		258,000	
Approach speed, in kts.	83		74		68	
Runway length, in ft.	2,180		1,940		1,770	
Stage length, in st. miles	250	500	250	500	250	500
Fuel consumption for the trip, in Imp. gal. ...	254	460	279	508	309	560
Block time (cruising at 220 kts. approx.), in hrs. ...	1·20	2·20	1·20	2·20	1·20	2·20
Hourly cost, in £	57·3	57·3	59·4	59·4	62·1	62·1
Fuel cost, in £	23·9	43·2	26·2	47·7	29	52·6
Cost of the trip, in £	116	192·7	120·8	201·2	126·8	212·1
Cost of passenger/mile, in pence	2·67	2·22	2·78	2·32	2·92	2·44

FIGURE 11. Characteristics of four-turboprop aircraft having low wing-loadings.

AIRCRAFT HAVING A LOW WING-LOADING

One of the simplest approaches is obviously an aircraft fitted with powerful engines and having a low wing-loading, for instance, under 100 kg./m.² (20·5 lb./ft.²). This is an excellent solution for small size aeroplanes. The Dornier DO. 27 (Fig. 9) and, to a smaller extent, the Grumman Mohawk (Fig. 10) are indications that this approach may be successful.

It appears, however, that the actual achievement of an aircaft of this type becomes less and less feasible when the take-off weight grows. Very soon, the weight of the wing and its drag in cruising flight becomes prohibitive, entailing a very sharp drop of the economy.

These simple and comparatively rugged aeroplanes are well adapted to military missions, but they are terribly handicapped, in commercial utilisation, by regulations specifying appreciable safety margins on the take-off speed in case of engine failure, not only with respect to the maximum lift coefficient, but also to the minimum control speed with one engine failed.

For the sake of argument, an aircraft of this type has been considered, complying with the 50-seat requirement; the wing-loading and the power have been varied in order to reduce the approach speed, still maintaining about the same cruising speed. The results are outlined in Fig. 11, which shows the change in cost per seat-mile when the minimum speed is reduced.

FIGURE 12. Lockheed C-130 B.L.C.

This example will be used as a reference for the comparison of more advanced VTOL or STOL transports.

AIRCRAFT WITH BOUNDARY-LAYER CONTROL

In this domain, obviously more advanced technically, the control of the boundary layer allows lift to be built up high enough to achieve low minimum speeds, while still limiting the wing area to a reasonable value. This approach has already been the basis for interesting military aircraft and, in particular, combat aircraft. The technique generally used is to blow the boundary layer with compressed air bled from the compressor of the engine. This air can be obtained easily without the extra weight of a separate installation.

In certain cases, however, the air is obtained from separate units. In the field of transport aircraft the only practical achievement, so far, has been the Lockheed C-130 B.L.C. (Fig. 12). Even though this aircraft is an adaptation of an existing airframe which was not specifically designed for the purpose, the combined use of air generators for B.L.C. and of the propeller slipstream effect have outstandingly shortened take-off and landing ground runs. I think, however, that this configuration could be optimised by utilising by-pass jet engines on which the compressed air would be bled from the cold flow, giving the obvious advantage of having no influence on the overall thermal cycle of the hot part of the engine. A typical calculation has been made on the 50-seat example transport with B.L.C., the wing-loading being varied. The results are given on Fig. 13, demonstrating the value of this configuration.

It is of importance to note that this approach does not entail a major technological complication making it unacceptable for a transport aircraft. It assumes, however, that there exist by-pass jet engines having a power output well adapted to the programme. To avoid an expensive excess of power, it is advisable to have at

Wing-loading, in lb./ft.²	57		42		34	
Empty weight, fully equipped, in lb.	24,900		26,700		28,700	
Maximum take-off weight, in lb.	42,300		44,800		47,700	
TOTAL THRUST IN LB.	21,100		22,400		23,800	
C_A Cost of airframe, in £	170,000		178,000		185,000	
C_E Cost of power plant, in £	136,000		145,000		152,000	
TOTAL COST OF AIRCRAFT, IN £	306,000		323,000		337,000	
Approach speed, in kts.	78		67		60	
Runway length, in ft.	1,650		1,370		1,200	
Stage length, in st. miles	250	500	250	500	250	500
Fuel consumption for the trip, in Imp. gal. ...	525	755	573	836	624	925
Block time (cruising at 400 kts. approx.), in hrs. ...	0·76	1·33	0·77	1·35	0·79	1·37
Hourly cost, in £	65·4	65·4	68·1	68·1	70·3	70·3
Fuel cost, in £	49·3	71·0	53·9	78·7	58·7	87·1
Cost of the trip, in £	130·4	195·3	138·1	208·5	146·5	222·0
Cost of passenger/mile, in pence	3·0	2·25	3·12	2·41	3·38	2·56

FIGURE 13. Characteristics of transports powered by four ducted fan engines and fitted with B.L.C.

Note: At a given value of the wing loading, the removal of B.L.C.:—Increases runway lengths by 30 per cent: Decreases aircraft cost by 3 per cent.: and Decreases cost of passenger mile by 2 per cent.

least three or four engines. By having several engines, it is also possible to improve the level of safety, liftwise, by having an appropriate configuration of the blowing system.

What are the limits of this technique?

In the field of low speed, the boundary layer control technique simply offsets the problem of wing loading, since it increases the maximum lift coefficient by 50 per cent compared with good flaps. The minimum speed is therefore reduced by some 20 per cent. On the other hand, this technique can easily be adapted to large size airframes, since two aircraft having the same lift coefficient, the same wing-loading and the same thrust loading have approximately the same take-off length.

The mass flow required by the boundary-layer control will, therefore, be proportional to the wing area and to the thrust, so corresponding to the same percentage of bleed from the engines. Also, the nozzle areas will be in proportion. It may be that with such a technique we will see some time very big B.L.C. transports serving trunk lines like Paris-London in particularly inexpensive conditions.

CONVERTIBLE AIRCRAFT

This covers many types of aircraft in which the main propulsive units substantially contribute to the lift. In this very broad sense, most STOL and VTOL aircraft can be considered as convertible. It is to be noted that the propulsive unit can be a propeller as well as a jet engine or any intermediate thrust-delivering device such as a ducted propeller. Many approaches are possible to ensure the transition of the power plant from its propulsive function to its lifting function.

We will not consider further aircraft of the "tail-sitter" type, which seem to be difficult to adapt to commercial air transport. We can then consider two main lines along which developments have taken place.

In the first type of machine, the propulsive elements are rotated. This has been successfully achieved with machines such as the Vertol 76 Tilt wing test vehicle (*see* Fig. 14) or the old Bell experimental vehicle with two tilting jet engines.

The other approach is to deviate the propulsive jet (propeller slipstream or pure jet). This deviation can be made by flaps, vanes or rotating nozzles. Of this type

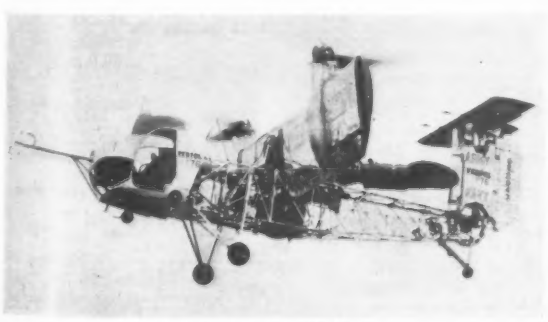


FIGURE 14. Vertol 76.

FIGURE 15. Breguet 940.

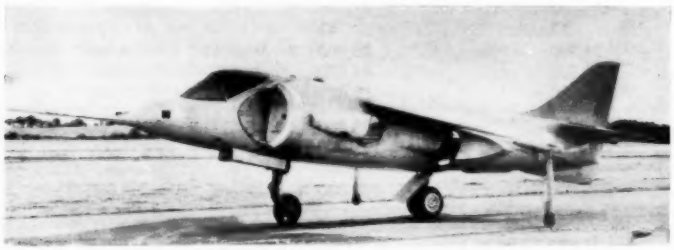


FIGURE 16. Hawker P-1127.

are the deflected slipstream aircraft such as the Breguet 940 (Fig. 15), the Hawker P-1127 (*see* Fig. 16). This latter aircraft uses an engine which has been especially developed for V/STOL aircraft by Bristol Siddeley, the BS-53. Of course, there may be many intermediate solutions which often offer a satisfactory compromise. For instance, tilt-wing aircraft have been proposed, where the wing is still fitted with flaps to improve the flexibility of operation of the aircraft.

In another area, I may mention new possibilities offered by the combination of jet engines with lifting fans driven by the exhaust jet during the hovering phase. This type of lifting power plant, invented by Louis Breguet some years ago, has been developed by the U.S. General Electric Company, in particular, under the direction of Mr. Kappus. In France, Messrs. Hurel and Bertin are designing a small VTOL based on this principle.

All these convertible aircraft have a common feature: since a high lift thrust is necessary at take-off, the power available for the cruising flight is high. Thus the speed is a by-product of V/STOL capability.

It appears, therefore, that this approach to the problem of a satisfactory short range transport seems to be sound. It is nevertheless necessary to evaluate in more detail the problems of safety and economy.

Safety-wise, the utilisation of the power to build up the lift partially, or totally, can be accepted only if every precaution has been taken to avoid uncontrollable motions in case of engine failure. It is, therefore, necessary that the lift be achieved symmetrically and with an appreciable safety margin. The value of this margin will be specified in detail in future Air Regulations, but at present one is limited to assumptions.

The "fail-safe" characteristics may entail very complicated refinements or very expensive procedures. For example, in lifting jet engine configurations, it may be prescribed to throttle back or even stop entirely the engine symmetrical to the failed unit, in order to avoid uncontrollable rolling motion.

Before discussing the economics in any detail, it is necessary to look into the technological configuration of those aircraft. It appears that certain solutions, which may well be adapted to combat aircraft, are impossible for transport machines because of installation difficulties. Also, the economy will certainly depend on the prescribed conditions of vertical or of short take-off and landing.

It would be necessary to make extensive surveys and, eventually, some practical tests of given programmes to make an accurate comparison between the various types of convertible aircraft. I will restrict myself to an example: the effects of the short take-off requirements on the economy of the deflected slipstream aircraft. Fig. 17 gives the conclusions of this work based on the same 50-passenger programme previously considered.

UTILISATION OF LIFTING JET ENGINES

Recent developments and, in particular, the outstanding achievements of Rolls-Royce in the field of small engines, have made possible the concept of an aircraft in which auxiliary jet engines partially or totally lift the aeroplane; the auxiliary units might be entirely independent from the main engines normally used for propulsion.

The remarkable demonstration of the Short SC-1 (Fig. 18) at Farnborough in 1960, proves that this approach is sound. This solution has certainly a great flexibility in the type of performance it allows. The

Wing-loading, in lb./ft.²	53		39		32	
Empty weight, fully equipped, in lb.	26,300		28,300		30,100	
Maximum take-off weight, in lb.	41,800		44,600		46,400	
TOTAL POWER, IN H.P.	3,940		4,180		4,560	
C_A Cost of airframe, in £	172,000		181,000		189,000	
C_E Cost of power plant, in £	71,000		74,000		79,000	
TOTAL COST OF AIRCRAFT, IN £	243,000		256,000		268,000	
Approach speed, in kts.	68·2		57·8		52·5	
Runway length, in ft.	1,370		1,210		970	
Stage length, in st. miles	250	500	250	500	250	500
Fuel consumption for the trip, in Imp. gal.	268	477	284	508	309	554
Block time (cruising at 220 kts. approx.), in hrs.	1·20	2·20	1·20	2·20	1·20	2·20
Hourly cost, in £	60·4	60·4	62·3	62·3	64·6	64·6
Fuel cost, in £	25·2	44·9	26·7	47·8	29 1	52
Cost of the trip, in £	121·0	200·6	124·6	208·0	129·9	217·2
Cost of passenger/mile, in pence	2·80	2·32	2·88	2·40	3	2·51

FIGURE 17. Characteristics of deflected slipstream convertible aircraft.

FIGURE 18. Short SC.1.

safety problems are similar to those mentioned for convertible aircraft but the safety level is probably easier to obtain, since the lifting thrust is shared among several small units.

However, for a transport aircraft, there is a problem involved in accommodating the rows of small lifting engines into a conventional type of airframe. This is probably easier within the futuristic shape of the long range supersonic air liner, to which they are particularly well adapted. According to an evaluation made by Rolls-Royce, it appears that the additional weight of those engines is more than off-set, on long range flights, by economy on the weights of the wing and the fuel.

The comparatively low weight and low cost of the lift engines permit combinations with jet deflection on the main propulsive engines which may offer characteristics well adapted to the short/medium range transport.

In Fig. 19 two types of transport are compared:

(*a*) a VTOL machine powered by two propulsive jet engines with deflection and six auxiliary lift engines;

(*b*) a STOL aircraft with two main and four lift units; two different wing-loadings have been evaluated.

The results show that there is little difference in economy between STOL and VTOL, this being due to the necessary power, as demonstrated below.

However, in view of the required power, changes on the cost of the engines and also requirements on fuel reserves have a heavy effect on this economy.

Conclusion

POWER REQUIREMENTS FOR V/STOL AIRCRAFT

Although the weight of the lift engines is steadily decreasing, the economy is closely dependent on the required power. This power is determined from the take-off conditions, in particular, in giving full allowance for the failure of one engine.

In order to evaluate those requirements, a chart (Fig. 20) has been plotted: it gives a good first approximation of the take-off distances of a given configuration. In this chart, the take-off distance takes into account the clearance of the standard obstacle. It is seen that the take-off distance is a function of two parameters:

$$\frac{P}{SC_{L\max}} \quad \text{and} \quad \frac{P-T_v}{T_h}$$

where:

- P take-off weight
- S wing area
- $C_{L\max}$ maximum lift coefficient actually used, taking into account the specified margins
- T_v vertical component of the equivalent thrust
- T_h horizontal component of the equivalent thrust

T_v and T_h take into account all losses, the aerodynamic drag, the ambient conditions and, eventually, the failure of one engine.

	VTOL		STOL		STOL	
Number of propulsive jet engines (used for lift by jet deviation)	2		2		2	
Number of auxiliary lift jet engines	6		4		4	
Wing-loading in lb./ft.²	76		65		58	
Empty weight, fully equipped, in lb.	27,000		25,000		25,800	
Maximum take-off weight, in lb.	48,500		48,500		50,000	
TOTAL THRUST, IN LB.:						
Main engines	17,000		12,600		12,200	
Auxiliary lift engines	51,000		25,300		25,900	
C_A Cost of airframe, in £	174,000		179,000		183,000	
C_E Cost of power plants, in £	190,000		110,000		114,000	
TOTAL COST OF AIRCRAFT, IN £	364,000		289,000		297,000	
Approach speed, in kts.	0		56·5		53	
Runway length, in ft.	0		1,090		1,020	
Stage length, in st. miles	250	500	250	500	250	500
Consumption, in Imp. gal.	778	1,070	760	1,110	792	1,160
Block time (cruising at 400 kts approx.), in hrs.	0·77	1·29	0·86	1·45	0·87	1·48
Hourly cost, in £	89·9	89·9	71·0	71·0	72·5	72·5
Fuel cost, in £	73·2	100·5	71·2	104·2	74·5	108·8
Total cost of the trip, in £	165·9	239·9	156·4	232·1	161·8	241·3
Cost of the passenger/mile, in pence	3·83	2·77	3·61	2·68	3·74	2·78

FIGURE 19. Characteristics of transports powered by combinations of propulsive and lift jet engines.

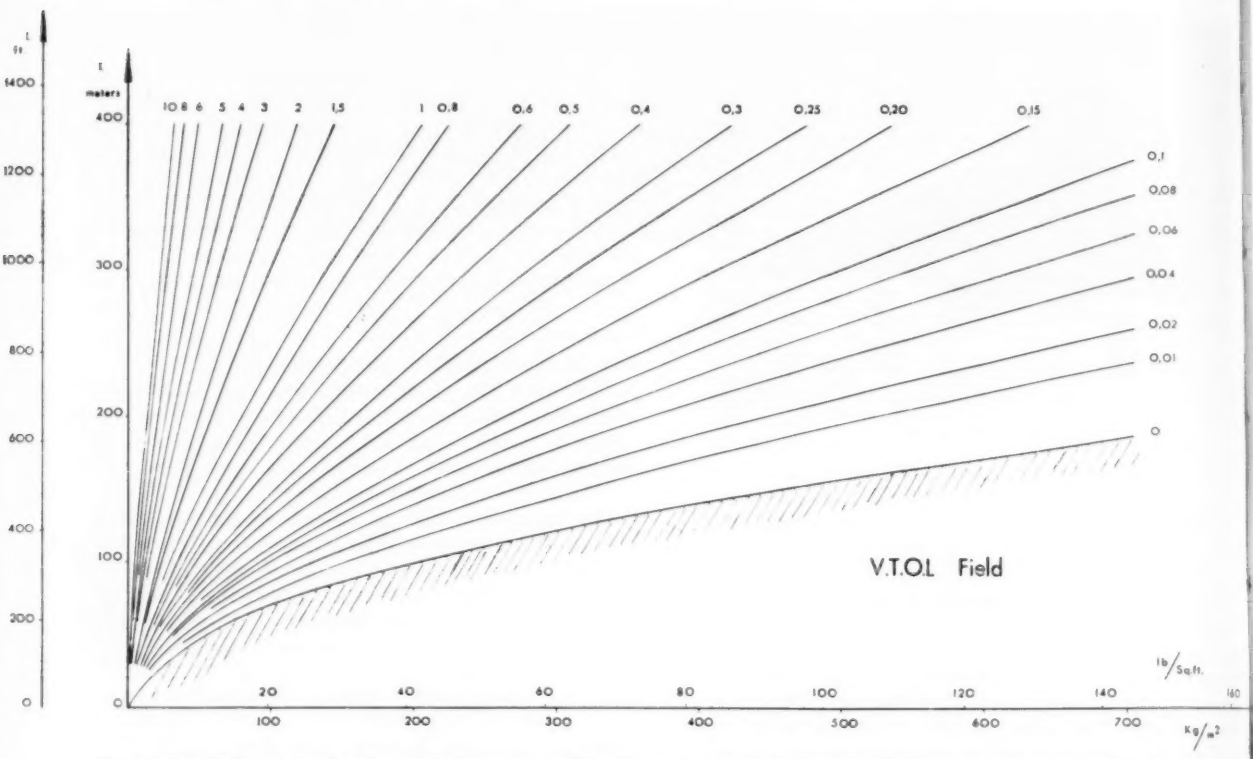


FIGURE 20. Take-off lengths chart. Optimum take-off length to clear a 50 ft. obstacle. Each curve is characterised by $P - T_v/T_h$.
P = Gross weight. T_v = Installed vertical thrust. T_h = Installed horizontal thrust.

Figure 20 shows the foregoing various configurations considered and it can be concluded from this chart:

(*a*) that aircraft having a high wing-loading and little or no high lift devices (where P/SC_{Lmu} is high), have to be over-powered and take off vertically. Otherwise, the take-off distance may easily become prohibitive.

(*b*) aircraft having efficient high lift devices and a lower wing loading, on the contrary, are much less sensitive to changes in ambient conditions, loss of one engine, and so on.

(*c*) the moderate amount of extra power required by the propeller-STOL aircraft is entirely used for cruising at a well adapted speed; in the case of the jet-lifted aircraft, the extra power is much too large and a certain number of engines have to be stopped in cruise flight.

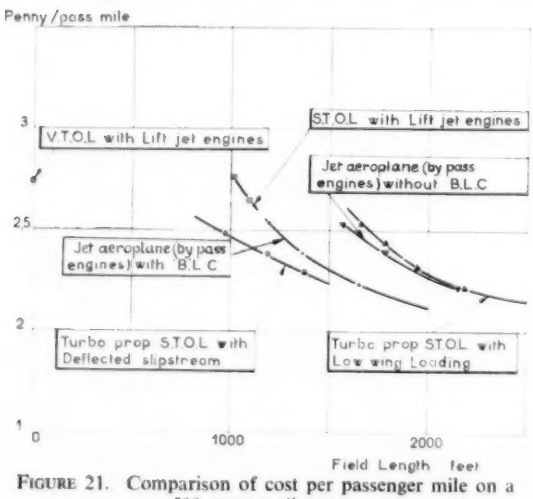


FIGURE 21. Comparison of cost per passenger mile on a 500 statute mile stage.

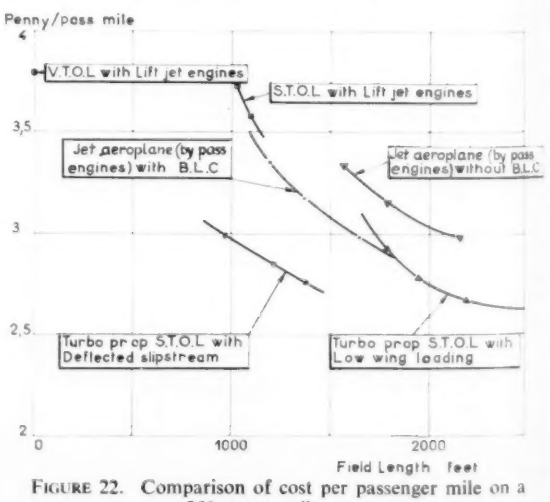


FIGURE 22. Comparison of cost per passenger mile on a 250 statute mile stage.

COMPARISON BETWEEN STOL AND VTOL CONFIGURATIONS

The economy of the various solutions mentioned, adapted to the 50-passenger transport project, is plotted on Figs. 21 and 22, giving the cost per seat-mile plotted against runway lengths.

The required runway length is the larger of two figures:

Take-off distance from full stop to clearing a 35 ft. obstacle, with engine failure at a critical point;

1/0·6 the landing distance from 50 ft. to full stop.

Incidentally, this demonstrates that, in order to have consistent performance, the STOL aircraft must have landing distances substantially shorter than its take-off distances and, nevertheless, achieve an excellent touch-down accuracy.

The graph for a 500 statute mile stage length shows that the use of the power plants to assist in supplying the required lift permits a substantial decrease in runway lengths, while still maintaining the cost of the seat-mile at a reasonable level.

The same graph, corresponding to the 250 statute mile stage length shows how favourable is the economy of the propeller-driven aeroplane based on the deflected slipstream concept, as compared to other techniques since, on such short hauls, the jet-propelled aeroplane is very little helped by its higher speed (assumed to be 400 kts. (460 m.p.h.) instead of 220 kts. (253 m.p.h.) for the turbo-prop machine).

This is why we think, in the present state of the art, that the propeller convertible STOL aeroplane gives a satisfactory answer to the proposed service.

These conclusions will probably be altered in a few years because of further technical developments; but I think that a first generation of propeller-driven STOL transports can give a spectacular impulse to short range air traffic.

PART III
FRENCH EXPERIENCE: THE DEFLECTED SLIPSTREAM TRANSPORT

I have outlined briefly various solutions to the problem of V/STOL short range passenger transports. Many achievements have been made and important experimental work has been conducted in the United Kingdom as well as in the United States. In England, in particular, the latest engine developments are most remarkable.

In France, we have probably been restricted to a more modest approach but I would like to outline some of the valuable achievements made in France.

Many years ago, the French Aeronautical Industry started looking into the development of power plants, and evaluating the future configurations. I will mention only the encouraging results obtained on boundary layer control both by Dassault on the "Etendard IV" and by Breguet on the "Vultur" mixed-power Fighter. I should also mention the S.N.E.C.M.A. projects, flying "Atar" and "Coleoptere." These, however, were aimed towards high performance military aeroplanes. In any case, outstanding British development work, both in the field of boundary layer control and of lifting jets, make these subjects very familiar to you all. I think, nevertheless, that France has been gathering original and sound data from its extensive programmes on deflected slipstream transports.

We have seen that such aircraft can be of interest and that they can find applications in short or medium range air services. The value of our programme is that it has not been limited to the evaluation of a principle. The development of the systems has been made in all details and is now giving birth to an aircraft ready to go into production.

The Breguet "94" Family

I would like first to point out that, in achieving such an aircraft, Société Breguet has limited its ambition to the STOL capability without, at least for the present, attempting to hover. Due to the fact that the velocities (aircraft velocity and slipstream induced velocity) can be added the deflected slipstream concept is particularly well adapted to STOL operation (Fig. 23). Also, it has been possible to discard the many expensive and unreliable devices required to stabilise a VTOL aircraft. Nevertheless, we were still facing many difficulties in utilising the power to build up part of the lift.

These difficulties have been solved, one after the other, in ten years of theoretical and wind tunnel studies and almost three years of flight testing of the comparatively large Breguet 940.

DESCRIPTION OF THE "94" FAMILY AIRCRAFT

Figure 24 is a general layout of the medium transport, Breguet 941, and Fig. 25 presents the main characteristics of four aircraft of that family:—

Breguet 940, experimental.
Breguet 941, commercial or military cargo aeroplane.
Breguet 942, passenger transport.
Breguet 945, commercial or military light cargo aeroplane.

In developing those aircraft, Breguet has constantly endeavoured to rely on means as simple and as safe as possible and, in particular, upon mechanical rather than electrical or electronic devices.

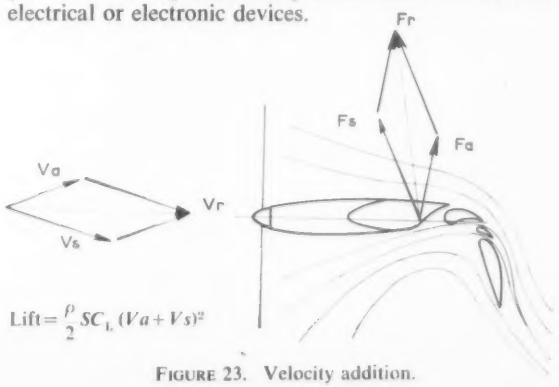
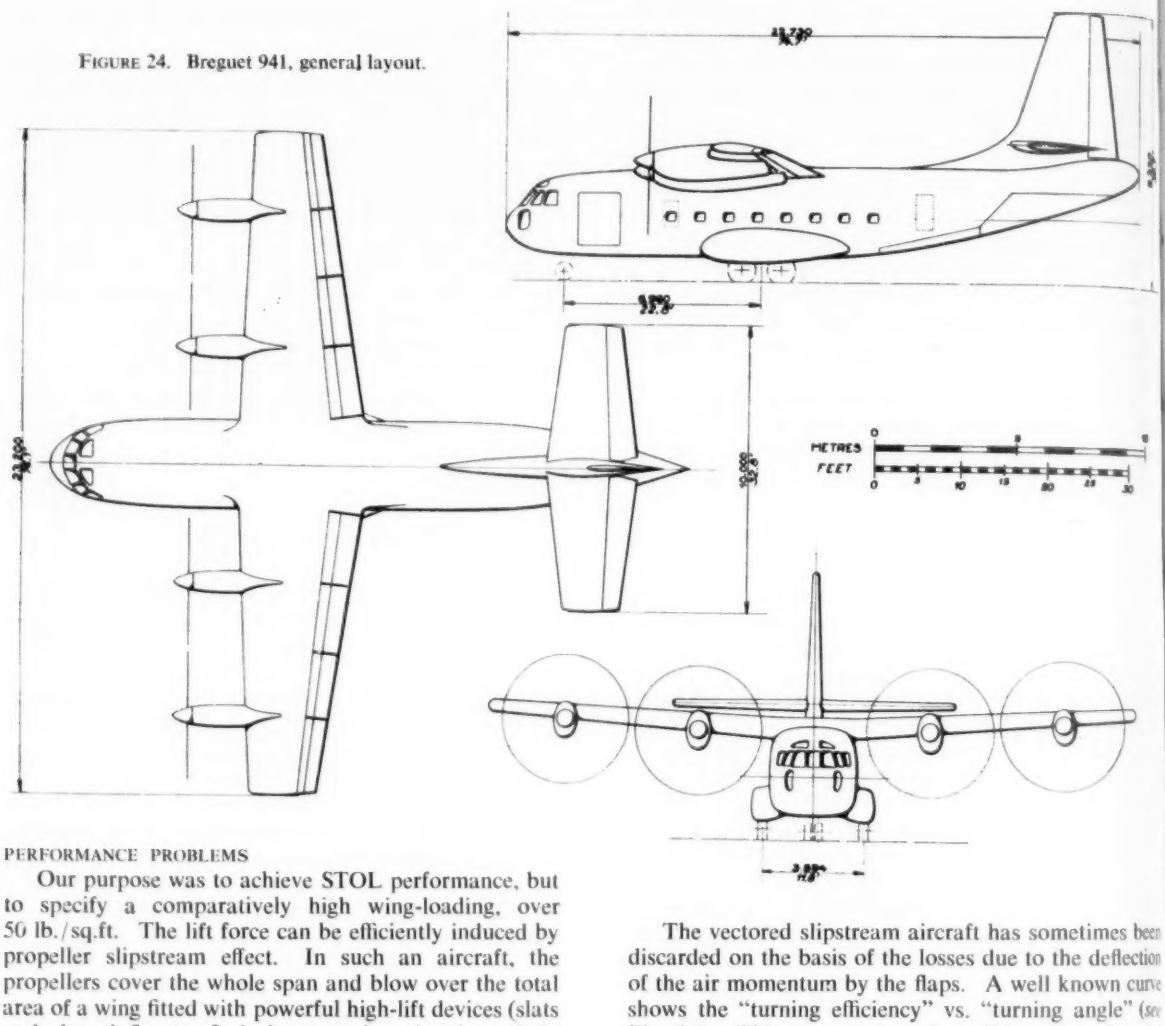


FIGURE 23. Velocity addition.

FIGURE 24. Breguet 941, general layout.



PERFORMANCE PROBLEMS

Our purpose was to achieve STOL performance, but to specify a comparatively high wing-loading, over 50 lb./sq.ft. The lift force can be efficiently induced by propeller slipstream effect. In such an aircraft, the propellers cover the whole span and blow over the total area of a wing fitted with powerful high-lift devices (slats and slotted flaps). It is because the wing is entirely within the propeller slipstream that this aircraft has sometimes been called "Integral."

The vectored slipstream aircraft has sometimes been discarded on the basis of the losses due to the deflection of the air momentum by the flaps. A well known curve shows the "turning efficiency" vs. "turning angle" (see Fig. 26). This concept is only valid at zero forward speed and is very misleading. Our experience has shown that it is possible to operate with flap deflection over

	940	941	942	945
Mission	Experimental	Cargo/Passenger	Passenger	Light Cargo
Length	50 ft.	74·7 ft.	76·8 ft.	54·5 ft.
Span	58·5 ft.	76·1 ft.	76·1 ft.	66·8 ft.
Wing area	512 sq. ft.	887 sq. ft.	887 sq. ft.	594 sq. ft.
Capacity	——	14,000 lb./48 passengers	50 passengers	7,700 lb./3,300 lb.
Engines	4 Turbomeca Turmo II	4 Turbomeca Turmo IIID	4 Turbomeca Turmo IIID	2 Turbomeca Turmo IIID
Total power	1,600 CV	5,000 CV	5,000 CV	2,500 CV
PERFORMANCE:				
Take-off at	15,400 lb.	45,000 lb.	45,000 lb.	22,000 lb.
Ground run ...	280 ft.	650 ft.	650 ft.	330 ft.
From stop to 50 ft.	620 ft.	1,000 ft.	1,000 ft.	750 ft.
Landing at	15,400 lb.	41,000 lb.	41,000 lb.	22,000 lb.
Ground run ...	200 ft.	410 ft.	410 ft.	200 ft.
From 50 ft. to stop	520 ft.	820 ft.	820 ft.	530 ft.
Cruise				
Cruise speed ...	——	220 kts.	220 kts.	210 kts.
Range at max. payload	——	375/700 st. miles	700 st. miles	375/925 st. miles

FIGURE 25. Characteristics of the Breguet STOL transports.

90°, still having a satifsactory efficiency in STOL conditions. In addition, one should not give too much importance to the significance of such an efficiency, because in all practical aircraft configurations the slightly greater power required is largely off-set by the simplification of the mechanisms. One should not forget that with the new turbines, the power is comparatively inexpensive from the point of view of weight, while this power is entirely used in cruise conditions to achieve higher cruising speeds.

Actually, most of the difficulties are encountered, not during take-off which is an accelerated transient configuration, but in landing. The idea is to utilise power in approach. But, if the aircraft is to remain at a reasonable attitude, the thrust of the propellers is to be compensated for by drag; otherwise, although the deflected slipstream aircraft can fly at low minimum speed, in that configuration it has a very low angle of descent, or even, with more power, climbs.

The Aerodynamics Department of Breguet was then in the paradoxical position of having to build up more drag—drag which is usually the aerodynamicist's personal enemy!

Here is their approach to the problem:

As is probably known, for safety reasons on which I will comment later, the four engines and the four propellers are interconnected by a shaft. The idea has been to create induced drag or achieve an artificial reduction of the aspect ratio. In order to do this, the two external propellers are set at zero equivalent pitch, while all the available power of the four engines is transferred on to the two central propellers, thus largely increasing the blowing effect on the central part of the wing.

This configuration, that we call "transparency", permits a stabilised descent with over 60 per cent of the maximum power on the four engines, under steep slopes up to 20 per cent and at low speed less than 45 kts. (52 m.p.h.).

Just after touchdown, the aircraft must brake efficiently and any second spent in doing so means a big loss on the landing run, since the speed is still appreciable. In order to achieve efficient braking in a split second, the four propellers are reversed which has the effect of aerodynamically braking the aircraft and also, instantly, destroying the lift, thus allowing good braking effect on the wheels. There again, the interconnecting shaft is of assistance: since, at the moment of touchdown, the pitches of the outboard propellers are already zero, they go immediately into reverse pitch while the positive pitches of the inboard propellers are progressively reduced, then grow negative. At no time are the pitches of all the propellers zero, so that there is no tendency to over-speed and the engines do not have to be throttled back.

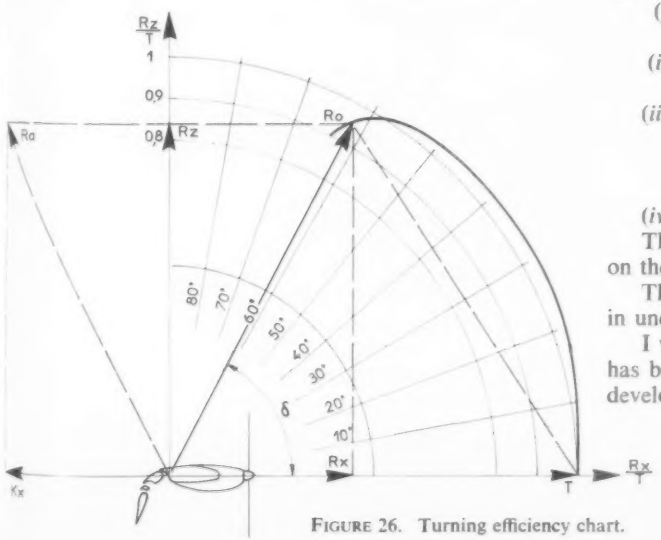


FIGURE 26. Turning efficiency chart.

FIGURE 27. Breguet 940 free flight model.

PROBLEMS OF STABILITY AND CONTROL

As already mentioned, these problems have been investigated in much detail, in order to rely entirely upon simple means. It has been possible to achieve satisfactory characteristics without utilising stability augmenters or other electronic devices. The overall development programme has been based on:—

(*i*) conventional wind tunnel models used to evaluate the stability derivatives;

(*ii*) a free flight model (Fig. 27), used to investigate the dynamics of the aircraft;

(*iii*) an analog flight simulator on which the data obtained from the models were translated in terms of aircraft characteristics and submitted to pilot's evaluation;

(*iv*) the aircraft itself (Breguet 940).

The results of the flight tests were again introduced on the flight simulator for interpretation or correction.

This systematic process has been extremely helpful in understanding the dynamic behaviour of the aircraft.

I would like particularly to emphasise the work that has been done on the free flight model which has been developed to an unparallelled perfection. Our model, a 1/7 scale model of the aircraft, has all the aircraft flight controls, including spoilers and control (separately or in combination) of the propeller pitches. In contrast to what is usually obtained from the experiments on cruder

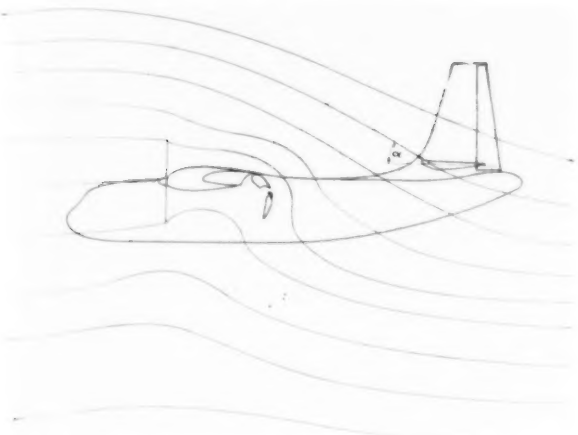


FIGURE 28. Angle of attack on horizontal stabiliser.

models, the results given by our free-flight model were quantitatively correct and in perfect correlation with the flight test data. I think that, in France, we have now acquired a very valuable technique which can be of great help in developing V/STOL aircraft.

So far as *lateral stability* is concerned, it soon became obvious that in the STOL configuration the dynamic behaviour of the ailerons was not acceptable. It is to be pointed out that the conventional stability and control criteria are not adequate to characterise such aircraft. In the case considered, even though the ailerons were initially inducing a rolling moment of the correct sign, they also induced a very important adverse yaw which, by building up sideslip, was almost immediately cancelling the aileron rolling moment by dihedral effect.

The solution has been to connect differentially the pitches of the outboard propellers to the stick when the aircraft is in STOL configuration. In this case, when the pilot starts banking the aircraft, he *increases* the pitch of the outboard propeller outside the turn and *decreases* the pitch of the outboard propeller inside the turn. By this, the differential thrust effect induces a direct yaw and the differential lift effect, induced by propeller slipstream, gives a direct roll so that the aircraft enters into a co-ordinated turn.

The main difficulty on *longitudinal stability* has been the tendency, in high power configurations, to experience horizontal stabiliser stall. It can be seen from Fig. 28 that for large flap deflection, the important downwash induces locally a large incidence on the stabiliser. This situation has been improved by having an adjustable horizontal stabiliser, as may be found now on a number of aeroplanes, and also by fitting the leading edge of this stabiliser with an inverted camber fairing.

Another point of importance is that aircraft of this type can tolerate quite large c.g. displacements. In cruise conditions, there is a comfortable margin on longitudinal stability due to the size of the tail surfaces determined, not from those conditions, but from the low forward speed efficiency. On the other hand, in a high-power configuration, the stability curve is quite flat. On a cargo aircraft, like the 941, the c.g. margin is over 10 per cent of the mean aerodynamic chord, a very commendable feature ensuring flexibility in loading.

PROBLEM OF SAFETY

This is where, I think, we have devoted most effort to achieve a safety level even higher than on conventional aircraft. It is for this purpose that the mechanical inter-connection of the engines and propellers (Fig. 29) has been prescribed. The advantages of this system are manifold:

1. In case of engine failure, the aircraft remains symmetrical, so that it is not submitted to the limitations of the minimum control speed.
2. With a four engined aircraft, if one engine fails the power of the remaining three units is distributed among the four remaining propellers. The propulsion efficiency is somewhat improved and even though the aircraft is losing 25 per cent of its power, it actually loses only 17 per cent of the slipstream, that is 17 per cent of the thrust and induced lift. With the inter-connection shaft, the four engined aircraft becomes a "pseudo" six-engined machine.

We have indicated the system of the transparency in which a large power is maintained on the engines, while a heavy induced drag is built up by reducing the pitch of the outboard propellers. It so happens that this configuration is extremely favourable from a safety point of view, in the case of a baulked landing. If, in this configuration, the pilot wants to fly round again, he can do so immediately by re-equalising the pitches of the propellers without changing the power. This gives almost immediately a comfortable rate of climb which can again be increased by partially retracting the flaps (which does not cause any decrease in lift) and by pushing forward the throttle.

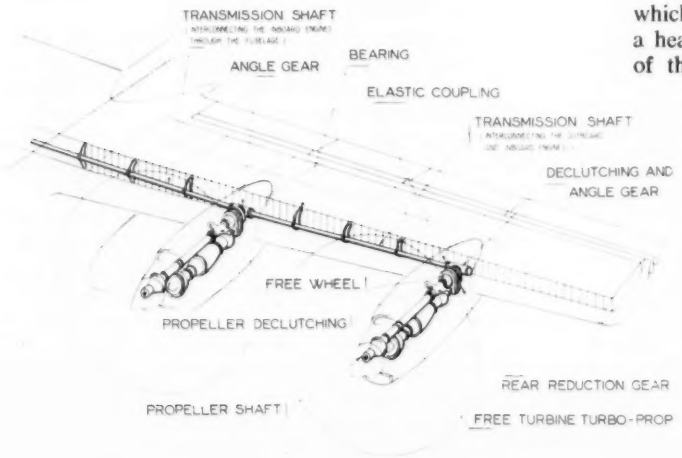


FIGURE 29. Inter-connecting shaft.

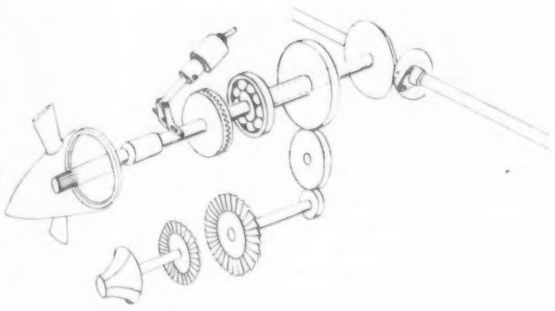


FIGURE 30. Transmission safety devices.

Of course, many precautions have been prescribed to avoid asymmetry on the flaps or on the propellers. I will not detail these systems, which are conventional, but I would like to comment on devices specified to overcome failure of the propeller pitch control or of the connecting shaft itself.

It is to be emphasised first that the case of a blade failure is highly improbable, since such failure occurs when the propeller is over-speeding and over-speed is impossible with the inter-connecting shaft.

Figure 30 shows the free wheels and clutches which overcome safely any type of failure of the gear boxes or of the shaft system. In addition, in case of failure of the propeller pitch control, the blades of the corresponding propeller are automatically locked. Experience has shown that the reserve of differential pitch action on the symmetrical propeller is sufficient to handle the aeroplane safely.

The studies of these safety systems have been very carefully evaluated in co-operation with European and American authorities, in order to work out the Certification Rules for aircraft of this type. I would like to take this opportunity of thanking them all for their assistance.

PROBLEMS OF OPERATION

As I said, this aircraft is easy and safe to handle, if not quite conventional. I think, however, that a fundamental characteristic of the STOL type of aircraft is that of landing accuracy.

Société Breguet does not intend to develop the STOL transport as an aeroplane as such, but to develop a certain number of auxiliary means which will make it a "transportation system" in the same sense as one currently thinks of a "weapon system". This is because this family of aircraft is not intended to operate from existing airports, but from almost any field. It must be mentioned at this point, that the structure and landing gear are designed to withstand rough ground operation. In co-operation with the European electronic industry, Société Breguet is developing simplified but accurate landing aids which should require reasonably small and inexpensive airborne equipment and a minimum ground installation. The aircraft will "haul" itself with a good accuracy and should achieve on small fields a reliability of service higher than is currently being obtained on the heavily equipped runways.

This is the family of aircraft to which Société Breguet is devoting much effort. The 941 is now being built in our prototype shops and should fly soon.

CONCLUSION

During fifty years, the aeronautical industry has devoted most of its efforts to improve what is certainly its foremost feature, speed. This has been done at the expense, sometimes very heavy, of other characteristics and, notably, of take-off lengths. In spite of the outstanding progress achieved, we must not lose sight of the price which is paid for such progress.

As speed has increased, the number of runways able to receive the new aircraft has decreased because of the tremendous investments necessary to open the required facilities. The air-travelling public, therefore, has been limited to people living in major cities or to those travellers who could come to those major cities by ground transportation means.

But enormous short-distance traffic is initiated everywhere, not only in big urban areas. It may be stated that, for the present time, an overwhelming majority of the public is quite unaware of the advantages of air transportation. The new techniques in the field of STOL and VTOL aircraft are about to give a practical, safe and economical answer to

FIGURE 31. Breguet 941.

this need for fast local traffic. There is, therefore, an enormous potential market for the air transport aircraft of tomorrow.

Procedures for traffic control to ensure safe and reliable service in all weather conditions must be established and enforced. The corresponding regulations should be prepared without delay to answer the growing demand. It must be emphasised, however, that similar problems were involved in launching jet traffic on a large scale and those problems have been solved.

I think, therefore, that I am not making an overstatement in saying that we are going to see, in the near future, a real revolution which will change, not only the traffic distribution of airlines, but also the economy of the world and even the political situation of many countries. This new tool will open to normal economic life many countries having possibilities, but handicapped in their development by lack of transport.

This new equipment, in its military applications, will also entail radical changes in strategical and tactical concepts, since mobility through a flexible and fast air transport system will be largely increased, thus solving most of the logistic problems.

Continuous efforts must still be devoted to this new family of aircraft, but we can be assured, from now on, that the success of this enterprise is within our reach.

Dr. Moult: They were all most indebted to General Ziegler for giving a most interesting lecture on what was, undoubtedly, a most important aspect of current aeronautical progress.

If short-range transport by air was to grow—and, as General Ziegler had pointed out, there was tremendous scope in this field—they had to face three major problems:—

Economical operation—otherwise they would fail to attract the traffic; A solution to the noise problem—otherwise the public would resist landing areas in populated districts, and Safety—which was paramount if traffic density in near-city areas was to increase.

Indeed, the traffic-control problems alone might demand a S/VTOL characteristic.

General Ziegler's lecture had shown that he had studied these problems most thoroughly and conscientiously. He had given them the benefit of a vast experience in the design and operation of aircraft for which they were most grateful. By tradition there was no discussion at the Blériot Lecture but he would ask Air Commodore Banks, Vice-President of the Society and the first Blériot Lecturer to propose the vote of thanks.

Air Commodore F. R. Banks: He knew of Henri Ziegler's work for France during the War but had never met him until immediately after hostilities, when he led a mission of his compatriots to this country to look into what had been done in aviation in the War and also, presumably, to prepare what France was to do to restore her place in post-war aviation. General Ziegler had great difficulties—indeed France had great difficulties—in those times because she had never really produced anything from the birthpangs of the Government of 1936 when the Aircraft Industry was nationalised. He thought the renaissance of the French Aircraft Industry since the War was truly remarkable. Their thinking and their ingenuity, in military aviation, in civil aviation and in missiles, had really put them at the top level. He thought that France had shown the World a great deal, in this post-war period.

The Lecture had been an interesting and a thoughtful one and he was always sorry that these memorial lectures, given to honour distinguished men like Louis Blériot, did not have a discussion. It was a timely lecture and they could have spent another hour and a half on its discussion. This particular phase of aviation which was coming upon them, VTOL—S/VTOL, reminded him of one of the, perhaps, many enlightened things Henry Ford had said in his ignorance at the time: when he was just about to go into aviation himself. Henry Ford said to someone who was showing him around some aeroplanes—in Detroit, he thought—" the aeroplane will be no good until it makes full use of its engine for landing."

He would ask them to signify in the usual way their appreciation of an excellent lecture and also of the very gallant gentleman who gave it.

After the Lecture a Dinner was given by the President and Council at which the following were present:—

Monsieur Henri Zeigler, C.B.E., 1961 Louis Blériot Lecturer, General Manager, Société Breguet.

K. L. S. Armandias, Representative of A.F.I.T.A. in Great Britain.

Dr. A. M. Ballantyne, T.D., B.Sc., Ph.D., Hon.F.C.A.I., F.I.A.S., F.R.Ae.S., Secretary, Royal Aeronautical Society; Air Commodore F. R. Banks, C.B., O.B.E., A.C.G.I., M.I.Mech.E., Hon.F.I.A.S., F.R.Ae.S., Vice-President, Royal Aeronautical Society, 1948 Louis Blériot Lecturer; A. D. Baxter, M.Eng., M.I.Mech.E., F.R.Ae.S., Member of Council, R.Ae.S.; Professor J. A. J. Bennett, D.Sc., Ph.D., F.R.Ae.S., Member of Council, R.Ae.S.; Jean Brocard, Louis Blériot Lecturer 1949 (Formerly of Société Breguet); H. Buckingham, Managing Director, de Havilland Engine Co. Ltd.; Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Honorary Treasurer, R.Ae.S.

Sir Sydney Camm, C.B.E., F.R.Ae.S., Past President, R.Ae.S.; Dr. W. Cawood, C.B., C.B.E., B.Sc., F.R.Ae.S., Member of Council, R.Ae.S.; Dr. J. S. Clarke, O.B.E., Ph.D., F.R.Ae.S., M.I.Mech.E., Director, Joseph Lucas Ltd.

L'Ingenieur General Noel Daum, Directeur Téchnique de Nord Aviation, 1959 Louis Blériot Lecturer; T. de Graaff, London Representative of Société Breguet.

L. G. Frise, B.Sc., A.F.I.A.S., F.R.Ae.S., Member of Council, R.Ae.S.

Sir George Gardner, K.B.E., C.B., D.Sc., F.R.Ae.S., M.I.Mech.E., Member of Council, R.Ae.S.; M. N. Golovine, M.B.E., A.C.G.I., F.R.Ae.S., Managing Director of A.T.S. Co. Ltd.

R. Hafner, F.R.Ae.S., Chief Designer (Helicopters), Bristol Aircraft Ltd., 1954 Louis Blériot Lecturer; Sir Arnold Hall, M.A., F.R.S., F.R.Ae.S., Past President, R.Ae.S.; H. Hardman, C.B., Permanent Secretary, Ministry of Aviation; Dr. G. S. Hislop, B.Sc., Ph.D., F.R.Ae.S., Member of Council, R.Ae.S.; Commandant Humbert, Assistant Air Attaché, French Embassy.

J. Jarry, President d'Honneur, A.F.I.T.A.; Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C., B.A., D.I.C., F.R.Ae.S., M.I.Mech.E., President Elect, R.Ae.S.

D. Keith-Lucas, M.A., F.R.Ae.S., M.I.Mech.E., Member of Council, R.Ae.S.

M. L. Marchetti, Technical Director Sud Aviation; P. G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., Immediate Past President, R.Ae.S.; M. B. Morgan, C.B., M.A., F.R.Ae.S., Member of Council, R.Ae.S.; Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), Ph.D., F.R.Ae.S., M.I.Mech.E., President, R.Ae.S., 1960 Louis Blériot Lecturer.

M. Pean, Ingénieur en Chef, Air France; M. de Pontfarcy, Ingénieur, Société Breguet; Henri Potez, President, A.F.I.T.A.; Captain J. L. Pritchard, C.B.E., Hon.F.R.Ae.S., Secretary, R.Ae.S., 1925-51.

M. Ricard, Directeur Téchnique, Société Breguet; Geoffrey Rippon, M.P., Parliamentary Secretary to the Ministry of Aviation; Sqn. Ldr. R. C. G. T. Rogers, D.C.Ae., A.F.R.Ae.S., Member of Council, R.Ae.S.; N. E. Rowe, C.B.E., D.I.C., B.Sc., A.C.G.I., F.R.Ae.S., M.I.Mech.E., Past President, R.Ae.S.; A. A. Rubbra, B.Sc., F.R.Ae.S., M.I.Mech.E., Member of Council, R.Ae.S.

Air Marshal Sir Herbert Spreckley, K.B.E., C.B., F.R.Ae.S., M.I.Mech.E., Member of Council, R.Ae.S.

W. Tye, O.B.E., B.Sc., F.R.Ae.S., Member of Council, R.Ae.S.

L. A. Wingfield, M.C., D.F.C., A.R.Ae.S., Solicitor to the R.Ae.S.

Large Rocket Engines for Space Vehicles and Missiles*

BY

S. K. HOFFMAN

(President, Rocketdyne Division, North American Aviation, Inc.)

SUMMARY: The history of Rocketdyne's activity in the field of large liquid-propellant rocket engines is outlined in a chronological review of applicable United States ballistic and space projects. Within security limitations, major rocket engine component improvements and general fabrication techniques are discussed. The trends and new developments in liquid-propellant rocket engine designs are presented and a forecast of future engines is made.

1. Introduction

The discussion is limited to large liquid-propellant rocket engines and essentially to Rocketdyne activity in this field. The paper is divided into four major categories: (1) a historical review of engine-missile projects, (2) a review of trends and new developments in engine design and manufacture, (3) a discussion of new, advanced engines in development at Rocketdyne, and (4) a forecast of future large, liquid-propellant rocket engines.

2. Historical Review

The development and production of large liquid-propellant rocket engines in America was fostered by the Navaho project. This weapon concept, initiated by the Air Force in 1947 and contracted to North American Aviation Inc., as weapon system manager, called for the development of a long-range supersonic ramjet cruise missile boosted to operating conditions by a large liquid-propellant rocket engine booster. These requirements dictated the development of a new rocket engine considerably larger than any previously developed. This effort was conducted by a specialised engineering group which has become the present Rocketdyne Division. One of the early flights of this rocket-boosted ramjet vehicle is shown in Fig. 1.

2.1. NAVAHO I

The design of the rocket engine for the Navaho system, while utilising the same propellants, incorporated many improvements and advances over the first large operational rocket engine, the German V-2.

The original engine proposed for the Navaho was to produce 75,000 lb. of thrust. The engine was designed to operate at a chamber pressure of 300 lb./in.^{2}, and required a turbine system capable of producing 835 horsepower. These requirements were met with an engine constructed, in some respects, along classical lines. This engine used liquid oxygen and an alcohol-water mixture. The double-wall thrust chamber and a steam generator which decomposed hydrogen peroxide to power the turbo-pump were early V-2 concepts incorporated in this engine.

It was at this point, however, that previous engine concepts were abandoned. The engine, its major components and the control system were entirely new. Where former systems were complicated interlocks of controls, the engine originally designed for the Navaho project (Fig. 2) was more simplified and uncluttered. A new thrust chamber design provided improved cooling characteristics for the increased heat transfer rate; an improved single injector design replaced the 18 separate injectors; and a new turbo-pump with uprated performance was used.

As a result of these changes, a significant improvement in operational dependability was effected. Early testing at White Sands, New Mexico, showed the life expectancy of a V-2 engine to be 10 to 15 short duration firings. An early Navaho engine was subjected to 115 test firings at White Sands Proving Grounds and at the Rocketdyne Propulsion Field Laboratory.

2.2. NAVAHO II

The specifications for the Navaho II, a later and larger version of the rocket-boosted ramjet missile, called for a cluster of two 120,000 lb. thrust engines. This requirement led to the development of the first completely modern lightweight engine.

The design of the 120,000 lb. thrust engine initiated

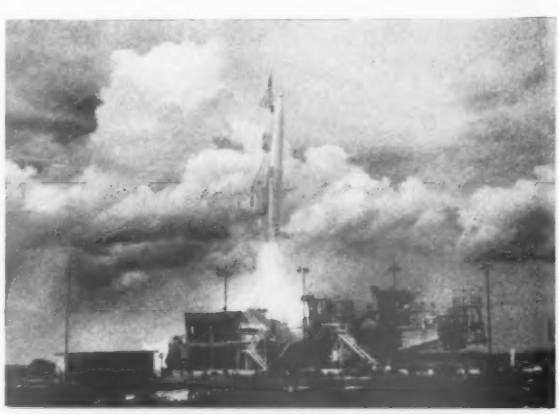


FIGURE 1. Navaho launching. The Navaho project was the first application requiring large liquid propellant rocket engines in the United States. The Navaho II vehicle is shown utilising two 120,000 lb. thrust rocket engines to boost the supersonic ramjet.

*The 5th Sir Henry Royce Memorial Lecture, presented to the Derby Branch of the Society on 7th November 1960.

several trends, the outgrowth of which is clearly evident in today's advanced engines. These basic trends were increased performance, greater simplicity, and reduced weight. Reduced weight and increased performance result in a more efficient engine capable of lifting larger payloads and accomplishing more ambitious missions; simplification results in a reliable engine which is easier to install, handle and operate.

A new, more efficient turbo-pump was incorporated into the engine design. To achieve the high flow rates and pressure heads required in the new engine, propellant pumps operating at a speed of 5,500 r.p.m. were developed. These pumps had a suction specific speed of 18,000, a value previously unheard of for this type of centrifugal pump design. A geared turbine was used to permit higher speed turbine operation, which provided high efficiency and a lightweight design.

This engine incorporated the first "bootstrap" power supply system which eliminated the third propellant normally required for gas generator operation. In the bootstrap design, the main propellants are bled back from the turbo-pump discharge lines to a gas generator which provides power to the turbine. This Navaho II engine also marked the initial use of tubular wall regeneratively cooled thrust chambers. This type of thrust chamber (Fig. 3) afforded a major reduction in engine weight, fabrication time and cost.

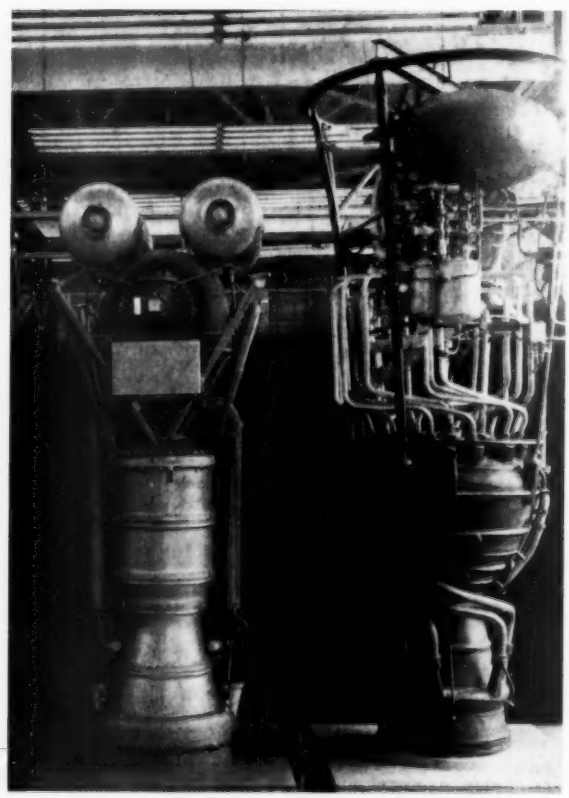


FIGURE 2. The Navaho I (Redstone) and V-2 Engines. The Navaho I engine system (*left*) features higher thrust and a simplified design compared to the earlier V-2 engine system (*right*).

2.3. NAVAHO III

The booster requirements for the Navaho III required a cluster of three engines of 135,000 lb. thrust, resulting in a booster stage with 405,000 lb. thrust.

The Navaho III engine was essentially an uprated version of the Navaho II design. The engine chamber pressure was increased to 500 lb./in.^{2} and the turbine was uprated to 2,400 horsepower. The Navaho III requirements advanced engine technology in two areas, propellants and thrust vector control. A significant increase in specific impulse was achieved by using kerosine fuel instead of the alcohol/water mixture. The combustion temperature contained within the regeneratively cooled walls was now up to approximately 6,000° F.

The three-engine cluster used hinged thrust chambers for vehicle thrust vector and roll control instead of the less efficient jet vane system. This requirement necessitated the development of large, flexible, high-pressure propellant lines and thrust chamber actuators. The Navaho III engine is illustrated in Fig. 4.

Although the Navaho project terminated before reaching operational status, the project left a rich technical legacy in the development of large liquid-propellant rocket engines and in such other fields as aerodynamics, thermodynamics, aeroelasticity, high-speed flight, inertial guidance, material processing and chemical milling.

2.4. REDSTONE

Final development of the 75,000 lb. thrust engine which had established itself as a dependable power plant, was threatened by suspension in early 1951 when tactical requirements of the Navaho programme changed.

FIGURE 3. Tubular wall thrust chamber.

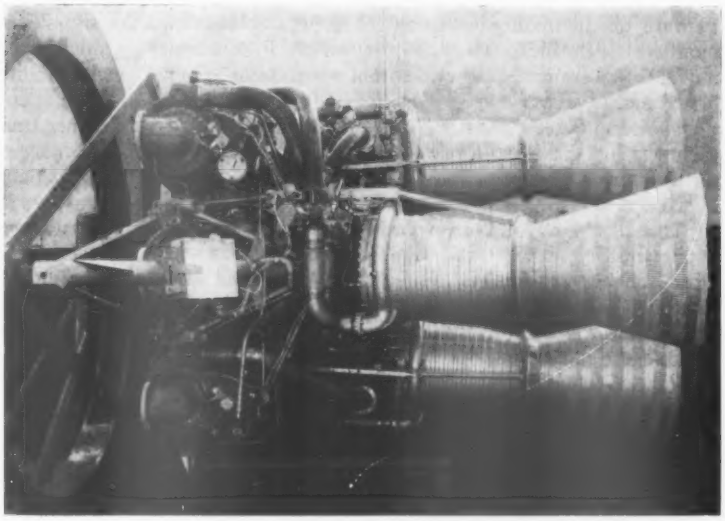


FIGURE 4. Navaho III Booster Engines. The Navaho III engine system, a cluster of three liquid oxygen/kerosine propellant engines, provided a total of 405,000 lb. thrust. The individual thrust chambers are hinged to provide missile attitude control.

Fortunately, this engine fulfilled the propulsion requirements for the Army's medium-range artillery weapon. In April 1951, a contract was awarded for continued development of this power plant for the Redstone missile. Under the contract terms, the engine was to operate at full capabilities for a duration of 110 seconds. In 1952, this engine entered production. Its first flight test was successfully completed in August 1953.

This engine has since been termed the "reliable workhorse" by the Army. Through its first 64 launches throughout a seven-year period, it has failed only once, during the third flight of the Redstone missile in 1953. Added recognition for this engine's reliability came after its use as the first stage booster for Explorer I, the first American satellite. The Redstone engine in the Explorer I functioned flawlessly after being in storage for 14 months. Hydyne, a Rocketdyne-developed high-energy fuel consisting of diethylenetriamine and unsymmetrical-dimethylhydrazine was substituted for the normal alcohol/water fuel to provide increased performance. Hydyne has been used in several of the Redstone space flights where additional performance was necessary.

Additional proof of this liquid-propellant rocket engine's reliability is the fact that this engine has been selected to launch the Mercury Astronauts in the first of the Free World's man-in-space projects.

2.5. ATLAS PROJECT

The next major rocket missile project was directed toward the development of an operational intercontinental ballistic missile. This project was initiated in 1953 by the Air Force with a research and development contract to Convair, a Division of the General Dynamics Corporation, as the weapon system prime contractor. It resulted in the production of the Atlas, the U.S. first operational ICBM.

The initial Atlas configuration, a one-and-a-half stage design, was based on a cluster of five 120,000 lb. thrust engines. The Atlas missile and its propulsion system was later radically changed as a result of breakthroughs in the thermonuclear field. Advances in bomb yields made possible significant reductions in the warhead weight and, consequently, the missile design payload. As a result, the Atlas ICBM was scaled down to the present three-engine, one-and-a-half stage configuration. (Many have claimed that this advancement in the nuclear field had the opposite effect in the rocket propulsion field by retarding the development of high-thrust booster systems in the United States.)

The Atlas design finally selected specified a booster propulsion system of two 150,000 lb. thrust engines supplemented by a 60,000 lb. thrust (80,000 lb. thrust at altitude) sustainer engine. Two 1,000 lb. thrust vernier engines were used to provide roll control and accurate thrust termination. The twin booster cluster would be jettisoned after a specified time. The sustainer engine would be ignited at sea level and operate essentially through propellant depletion, requiring an engine burning several times longer than any previous rocket engine.

These new engines incorporated thrust chamber gimbals, developed to provide single engine thrust vector control in any direction. This marked the first time that a gimbal system had been used in a high-thrust engine.

In the development of the Atlas engine system, a number of problems arose which required expeditious corrective action. Shrouded turbine blades were developed to eliminate blade fatigue failure. Improved seals were developed to eliminate the hazards of combustible leakage. New bearing designs were devised to extend bearing endurance.

A photograph of the Atlas at lift-off is shown in Fig. 5. The Atlas vehicle has achieved an outstanding flight record; the propulsion system an even more impressive record. In the first 60 flights, the propulsion system has performed successfully 56 times.

2.6. THOR/JUPITER PROJECTS

In November 1955, the United States Department of Defense established the requirement for an intermediate-range ballistic missile (IRBM) with a 1,500 nautical mile range. Development of advanced engines for the Army Jupiter and Air Force Thor was directed toward this goal.

Work on the Thor and Jupiter propulsion systems began after initial authority was given in November 1955. At this time the preliminary design of the Atlas engine was completed and experimental engines were in test. Both IRBM engines were based on the Atlas booster engine design. The first R and D engines for both Thor and Jupiter were delivered in mid-summer

1956 for missile mating test firings. This was only seven months after the inception of the programme. Production models of each engine followed within two months of the first R and D delivery.

Thor and Jupiter models began missile flight tests in early 1957—a little over a year after work had first begun on their engine systems. Both missiles have since produced a highly successful series of launches.

The IRBM engines incorporated in the Thor and Jupiter utilised an improved sequence for smoother and more reliable starting, as well as a miniaturised and simplified pneumatic control panel. Both engines incorporate regeneratively cooled, gimbaled thrust chambers. Bell-type nozzles were first used operationally with these engines. This nozzle configuration provides performance equal to the previous 15 degree half-angle conical nozzles, while reducing length and weight.

The Jupiter and Thor have also been used for many satellite and space missions as the booster stage. As of 5th October 1960, the Jupiter and Thor, together with the Atlas and Redstone, have been used as the booster stage for 26 out of 29 of the United States' successful satellites and space flights.

3. Major Trends

There are several aspects of rocket engine design that have historically received special attention in the product improvement programmes. Advancements in such areas as increased performance, reduced weight, engine simplification, improved fabrication techniques and higher reliability typify our effort over the past decade. Reliability may be considered as the major aspect in rocket engine design since it dictates the direction of all other trends in engine development. Whenever a design advancement will permit an increase in performance or a reduction in weight, the reliability of the advancement governs its use.

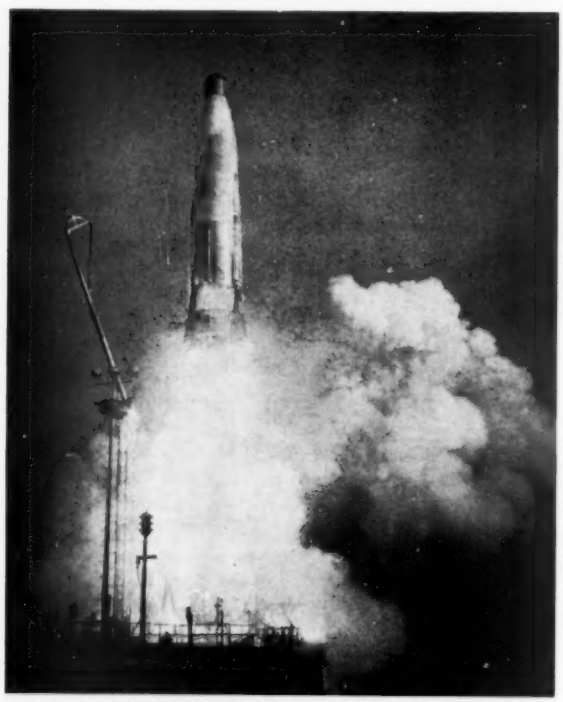


FIGURE 5. Atlas at lift-off. The operational Atlas vehicle has five rocket engines: two boosters, a sustainer, and two verniers. Including even the earliest test flights, 56 out of 60 of the missiles launched were successful with respect to engine system operation.

Reliability is a characteristic of the engine system established in the original design and in subsequent design improvements. In the initial design every aspect is analysed from a reliability standpoint. Based on engine testing, field reports and accumulated reliability statistics, a new engine design is evaluated to compare its design with problem areas in past engine designs. Potential weaknesses are determined and eliminated.

Throughout all phases of design and development, the component tests are analysed to locate any possible area in the design that can be improved to increase engine reliability.

Engine simplification is a prime example of how reliability can be built into a design. The reduction of the number of components through engine simplification eliminates potential malfunction areas. The new, advanced engine concepts to be used in a new engine design are proven in experimental test engines to ensure high reliability in the final production rocket engine.

Reliability is recognised as an over-all company effort. In all aspects of engine design the reliability is considered by the Reliability Board. This is a specific organisation which includes all sectors of management, engineering, and manufacturing, and provides direction and control over the programme. Within Engineering, a special department is continuously monitoring and evaluating the reliability standards of Rocketdyne engines: from the drawing board, during test and development, and through operational usage by the customer.

In the manufacture of the rocket engine, improved fabrication techniques and high quality control standards assure that the final delivered engine will have reliability designed into the system. For example, automatic numerically controlled machines provide great reproducibility and minimise possible manufacturing errors in components in the modern manufacturing plant.

3.1. PROPELLANTS

Major advances in the increase of performance for liquid-propellant rocket engines can be attributed to the use of new high-energy propellant combinations. High-energy propellants offer the most amenable method of increasing engine performance in significant strides. The initial high thrust rocket engines were designed for liquid oxygen/water-alcohol mixture propellants. The first advancement in propellant performance resulted from the switch to liquid oxygen/kerosine. The relative performance of these combinations is shown in Table I.

The liquid oxygen/kerosine propellant combination is used in the large rocket engines currently being produced: the Atlas, Jupiter, Thor and Titan engines. It has proved to be a highly successful combination from the performance, logistic, and economic standpoints.

TABLE I

PROPELLANT PERFORMANCE

Oxidiser	*Fuel*	*Specific Impulse, Sec.**
Liquid Oxygen	75 per cent Alcohol/ 25 per cent Water	267
Liquid Oxygen	Hydyne	291
Liquid Oxygen	Kerosine	286
Nitrogen Tetroxide	Hydrazine	283
Liquid Fluorine	Hydrazine	334
Liquid Oxygen	Liquid Hydrogen	388
Liquid Fluorine	Liquid Hydrogen	398

*Theoretical maximum for frozen equilibrium.
Optimum sea-level expansion from 1,000 lb./in.^{2} abs. chamber pressure.

The Redstone engine was designed for the liquid oxygen/water-alcohol combination. To provide increased performance without redesigning the engine system, a new fuel, Hydyne, was developed which could be directly substituted for the alcohol-water fuel. No engine design changes were required. Hydyne, a mixture of diethylenetriamine and unsymmetrical dimethylhydrazine, has the same physical characteristics of the alcohol-water mixture, but a significantly higher specific impulse (Table I).

Non-cryogenic (storable) propellant combinations have been investigated and tested to establish their feasibility for distinct applications where they may be required. Nitrogen tetroxide/hydrazine is typical of these propellant combinations and has a relatively high performance as illustrated in Table I. Investigation and testing of storable propellant combinations has been conducted since 1953. The 400,000 lb. thrust class engine as well as most of the other production engines have been satisfactorily tested with storable propellant combinations at high thrust levels.

High energy propellants, liquid oxygen/liquid hydrogen and liquid fluorine/liquid hydrogen, provide a great increase in engine performance. An intermediate high energy propellant, liquid fluorine/hydrazine provides somewhat less performance, but does not require the relatively large propellant volume associated with the use of hydrogen. The use of fluorine also has some disadvantage resulting from its toxicity.

The high energy liquid oxygen/liquid hydrogen is an excellent choice for future engine design. Fluorine toxicity is avoided, and the high performance offsets to a great extent the hydrogen volume required. Further advances in propellant performance will be achieved in the future; new high-performance non-cryogenic propellants will be developed and the possibility exists of developing exotic propellants whereby additional energy is added to the basic propellant by modification of its electron orbital arrangement.

3.2. THRUST CHAMBER DESIGN

Advancements in thrust chamber design have provided increased performance together with reduced weight and size. Improved injectors and increases in chamber pressure have favourably affected engine performance. Injectors now provide stable combustion with specific impulse values of approximately 100 per cent of theoretical. The use of a high chamber pressure design will permit a significant size and weight reduction. Advancement in injector design, thrust chamber cooling, and efficient high-horsepower turbo-pumps have made possible the efficient high chamber pressure systems. The use of high chamber pressures favourably affects sea level and vacuum engine operation. For missile upper stage engines, high chamber pressures will permit the use of a high nozzle area ratio (high performance) without over-increasing the engine size.

In early engine designs, a conical shaped expansion nozzle was used. It had a double-wall construction and was regeneratively cooled by the engine fuel. Tubular wall designs were introduced, which reduced weight and manufacturing time and cost. The nozzle shape was changed from the conical design to a bell-type nozzle which provided the same performance, but allowed a shorter nozzle with reduced weight.

Subsequent innovations in nozzle design, such as new nozzle contours, provided increased performance at all altitudes. The spike nozzle design, and variants thereof, offer further reduction in engine size and weight. These nozzle contours also lend themselves well to integration with the tank design.

3.3. TURBO-PUMP DESIGN

Increased performance has often dictated changes in component design which in turn has affected engine packaging. The turbo-pump design exemplifies this effect.

The Redstone engine utilised a low speed turbine directly coupled to the propellant pumps. Although pump suction specific speeds were higher than previously obtainable, turbine efficiency and size remained a major consideration at the low speed required by pump design.

Later engine models demanded higher pressure heads and flow rates; these, in turn, made necessary substantial increases in turbo-pump horsepower. The limited inducer design technology existent in the Redstone development period required that the pump be designed to operate at what is now considered a low speed. As a result, an efficient direct-drive turbine had an excessively large diameter and a high weight. Gears were required to provide a compact, high performance turbo-pump. For the Navaho, Jupiter and Atlas vehicles, geared turbo-pumps were utilised (Fig. 6).

Inducer development, the key to higher suction specific speeds, has been supported by continuous testing of new and improved concepts. The advancements in inducer development now permit efficient high-speed pump operation. The efficient high speed pump can be directly coupled to an efficient high speed turbine, eliminating the necessity of a geared drive. An additional benefit of inducer improvement is a reduction in the required pump inlet net positive suction head, thus lowering the required missile tank pressure.

Turbine performance has also been enhanced by the development of blade alloys that permit turbine operation with high temperature gases. Thus increased power can be attained without increasing the gas flow rate.

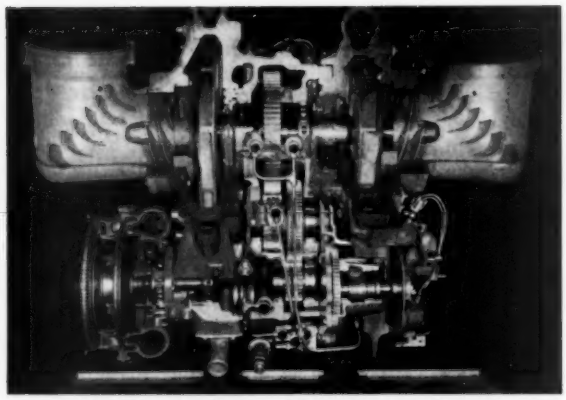


FIGURE 6. Jupiter geared turbo-pump cutaway.

Packaging of turbo-pump systems has also undergone considerable changes. In the early low chamber pressure designs, flexible propellant lines were used between the gimbaled thrust chamber and the stationary mounted turbo-pump. In the later, higher performance engines, the higher chamber pressure required made the use of large, high pressure flexible propellant lines undesirable. These designs favoured the mounting of the turbo-pump on the thrust chamber, moving the flex lines to the low pressure inlet side. This relocation was enhanced by the reduction in turbo-pump size and weight achieved in the advanced high speed, direct drive designs. Although this change in location increased the gimbaled mass, it provided greater overall engine simplicity and reliability.

A dual turbo-pump design, a separate unit for each propellant, may allow even more simplified packaging. This arrangement is especially desirable when optimum fuel and oxidiser pump speeds are widely separated as in hydrogen/oxygen engines. Pump inlets may be upright, permitting direct entry of the propellants, and turbo-pumps may be located symmetrically about the nozzle.

3.4. ENGINE SIMPLIFICATION

The rapid development schedules required for most current engines often preclude the luxury of attempting previously untried schemes. A series of experimental test engines is used for the sole purpose of testing new, previously untried, promising engine innovations. As new innovations are conceived, they are incorporated in these engines and tested. This testing has provided the evaluation of many items which have since become standard in engine designs.

In early engine systems, much of the complexity was caused by the starting and control techniques used at that time. Power to start the turbo-pump was supplied by a set of pressurised oxidiser and fuel tanks which fed the gas generator. Operation of the valves was provided by means of an electrical interlock system which controlled pneumatic actuators in the proper sequence. Igniters were used in the gas generator and thrust chamber to provide an ignition source for propellants. A pressurised oil tank provided turbo-pump lubrication.

Starting techniques and control methods have been simplified. Turbo-pump initial power is provided by a solid propellant starter or by tank head; either method eliminates the complex pressurisation tanks.

Propellant valves are actuated by fuel which is bled downstream of the turbo-pump discharge, and springs in the valve actuators are preset to open the valves at a given point during the pump discharge pressure build-up. This results in what is called the pressure ladder sequence. The valves open in a desired sequence, automatically, without recourse to any electrical or pneumatic control system.

Ignition of the gas generator propellants is accomplished from the turbine starter, or by a simple spark plug for tank head start. Main propellant ignition in the thrust chamber is initiated by a slug of hypergolic propellant which is injected into the combustion chamber before entry of the main fuel. Turbo-pump lubrication is accomplished with diluted fuel as the lubricant.

A "tap-off system" offers the possibility of eliminating the entire gas generator system. In the tap-off arrangement, Fig. 7, combustion gases are bled from the thrust chamber and used to drive the turbine, thus eliminating the conventional gas generator with its bootstrap propellant lines and controls.

A pyrotechnic squib, used to close the main liquid oxygen valve, permits the elimination of a vernier engine velocity trim in a missile system. The surges which result from the rapid valve closure are relieved by the burst diaphragm and by-pass valve line. Requirements for roll control may be satisfied by the use of a swivel nozzle at the end of the turbine exhaust duct. The swivel nozzle protrudes from the missile skin and is operated by a simple actuator within the missile.

The trend towards simplification of engine systems has resulted in the elimination of most of the requirements for servo controls. Simplification of the required servo loops has been accomplished by combining several engine functions into one servo loop. Previously, propellant valve sequencing and subsequent control functions were separated; now they are combined in one servo valve. Fig. 8 compares an early engine with a simplified version.

Another important feature of the current simplification trend has been minimisation of engine checkout

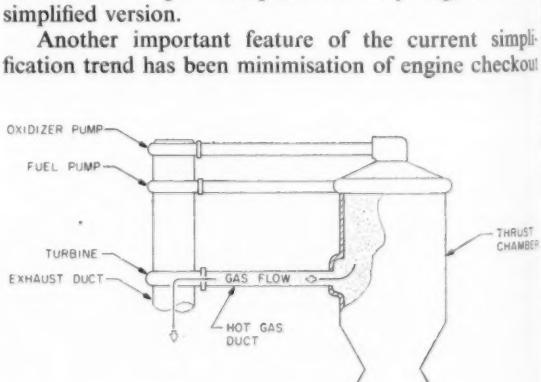


FIGURE 7. Schematic of tap-off concept. The tap-off concept which eliminates the necessity of a gas generator and its controls, utilises thrust chamber gases for turbine drive. It has been tested and proved feasible in experimental engines.

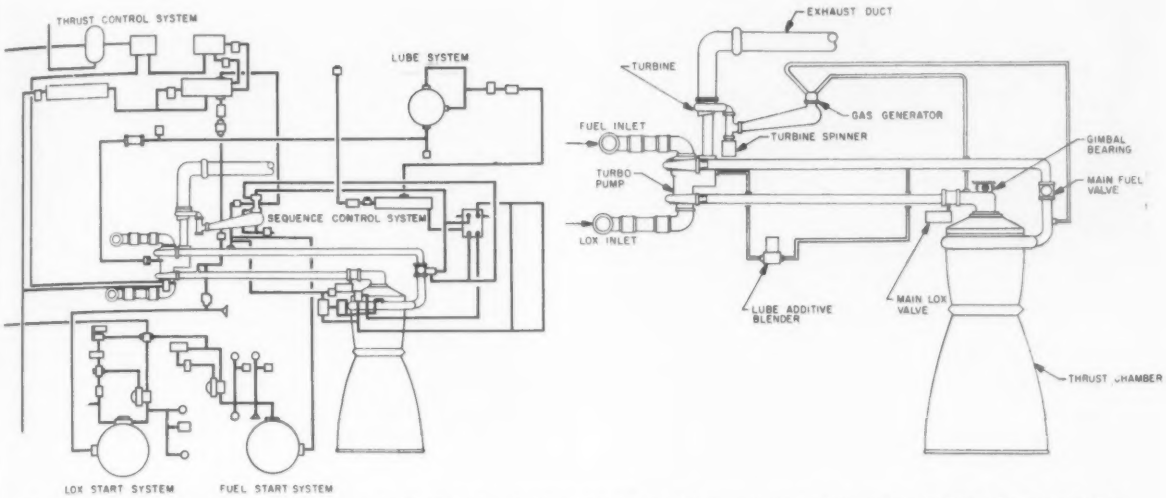


FIGURE 8. System schematics for an early (*left*) and a modern (*right*) liquid-propellant rocket engine indicate how simplification is being achieved in current designs. Major advances have been accomplished in the use of turbine spinners, diluted fuel for lubrication, turbine exhaust for roll control, and simplified engine control.

requirements before missile launch. As a result, much of the expensive ground support equipment can be eliminated. Checkout equipment for turbo-pump lubrication, component servicing, the jacket prefill function, engine flushout and purging, the electrical system and the external hydraulic supply have been reduced or eliminated by simplified engine systems.

3.5. FABRICATION

The fabrication of engines has improved considerably since the inception of the Navaho project. As a result of early research and development programmes, Rocketdyne has evolved basic fabrication techniques for manufacturing lightweight, high performance engines (Fig. 9). These methods of fabrication have proved to be versatile and readily adaptable to all design configurations.

Early engines pioneered the development of tubular wall thrust chambers. These tubes are placed on a mandrel, held in place with steel bands, and brazed to form a gas seal. Hydraulic tube forming is commonly utilised, and allows considerable design versatility.

To minimise thrust chamber weight and simplify construction, a resin-impregnated glass fibre wrapping technique has been developed. Designs utilising this technique have proved entirely satisfactory for use in these high temperature, high structurally loaded components. Thrust chambers have withstood repeated firings with no deterioration of the glass fibre-resin coating caused by heat or contact with chemicals normally encountered in liquid-propellant rocket engine testing. The glass fibre wrapping technique has been specifically applied to portions of several of the thrust chambers now being produced (Fig. 10).

Another area of thrust chamber fabrication which has been greatly improved is the tube brazing operation. Previously, tube brazing was accomplished manually and required skilled operators to obtain satisfactory results. The furnace brazing technique (Fig. 11) has now been developed to provide high-quality reproducible results. Brazing time for Atlas and Thor thrust chambers can be reduced from 365 hours to 6 hours by the furnace method.

Furnace-brazed thrust chambers have been tested repeatedly with no indication of failure. The furnace technique also offers definite advantages in fabrication of extremely large chambers where stainless or Inconel tubes do not lend themselves to hand-brazing operations.

In furnace brazing the tubes are assembled in a manner similar to that used in the hand-formed operation. The thrust chamber is then enclosed in an air-tight retort which is evacuated and then filled with an inert gas. In this manner, the brazing can be accomplished in a controlled, non-oxidising atmosphere.

Fabrication of many other engine components, such as injectors, turbo-pumps and gas generators, requires particular accuracy and close tolerances. The use of numerically controlled equipment (Fig. 12) results in

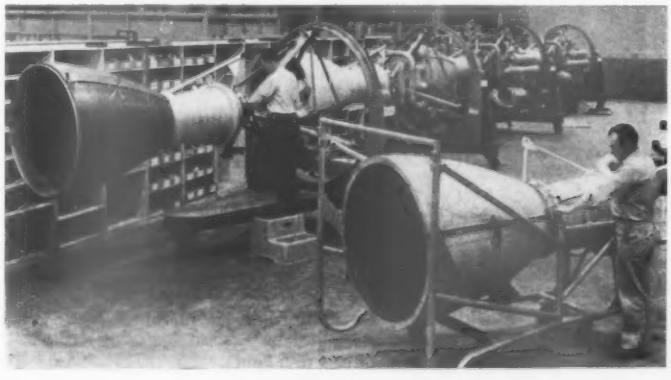


FIGURE 9. Engine production.

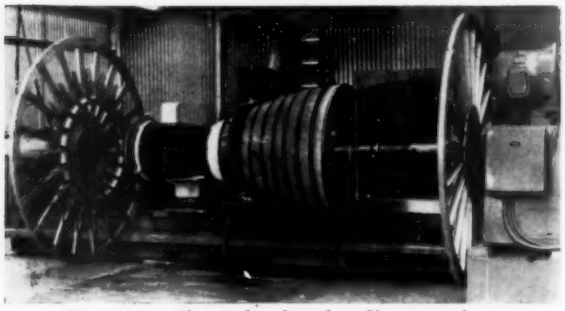


FIGURE 10. Thrust chamber glass fibre wrapping.

more accurate duplication of dimensions. With this equipment, the entire configuration of an injector hole pattern can be recorded on a punched tape, which directs the drilling and boring operation. Numerically controlled machinery is currently in use for drilling, milling and inspection operations. In most cases it reduces labour costs up to 25 per cent over conventional techniques.

In the production of rocket engine components, the need for new and economical techniques is always under investigation. The need for torque sensing devices has already been encountered and they are now used for drilling of special materials such as René 41. Under conditions of non-uniform torque, speed, or feed pressures, this metal develops local hot spots and portions of the metal become heat treated, losing considerable strength.

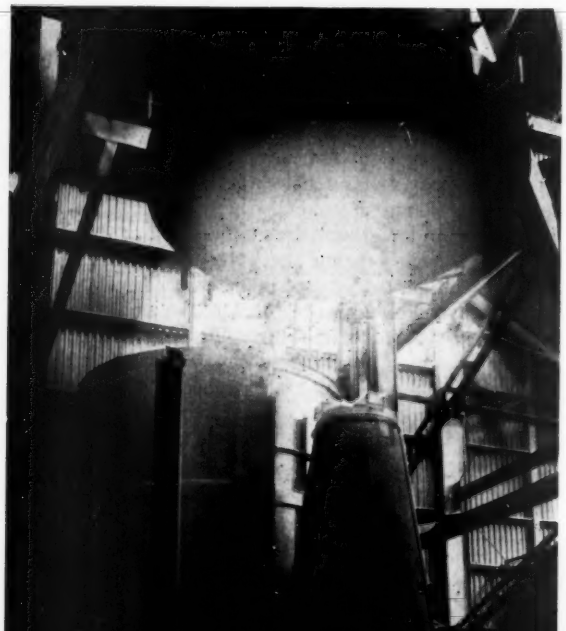


FIGURE 11. Use of the furnace brazing technique for tubular thrust chambers has reduced brazing time for a 150,000 lb. thrust chamber from 365 to 6 hours.

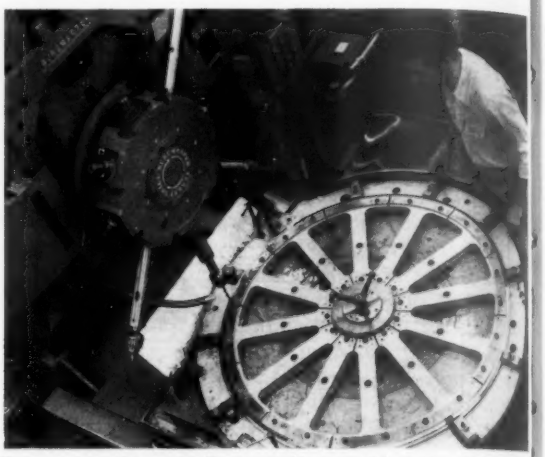


FIGURE 12. Numerically controlled machines have increased production, accuracy, and reproducibility of many engine components and are used in several phases of engine fabrication

3.6. INCREASED RELIABILITY, INCREASED PERFORMANCE AND DECREASED WEIGHT

Increased reliability is the prime objective of the new, advanced rocket engine design. Engine simplification has reduced the number of engine components, and the complexity of those remaining. Many potential malfunction areas have been eliminated. Improved fabrication techniques have eliminated minor manufacturing errors that in the past could have detracted from the reliability of the manufactured engine.

The performance and weight of the rocket engine exert a major influence on the capabilities of a given missile. During the past decade the improvement in engine performance has been outstanding. The use of high energy propellants has immensely increased our ability to obtain high specific impulse engines. The V-2 engine achieved a vacuum specific impulse of 237 seconds; new liquid hydrogen/liqiud oxygen propellant engines will have a theoretically attainable specific impulse somewhat over 400 seconds.

In the reduction of engine weight, engine simplification, elimination of components, shortening of lines and the reduction of trapped propellants were of major importance. Present thrust chambers weigh less because of their smaller size, and because of the lightweight, high-strength materials (such as fibre glass wrapping) used in their manufacture. The small, high-speed turbo-pumps weigh less than their predecessors. The results of these changes are evident in engine thrust-to-weight comparisons. Today's large engines produce more than 100 lb. of thrust for one pound of weight; the V-2 produced less than 30 lb. of thrust for one pound of weight.

4. New Large Engine Programmes

Several new, large, liquid-propellant engine systems incorporating many of the advanced features described, are under development at Rocketdyne for future space projects. The extent of design advancement depends somewhat on the date of design initiation and on the intended engine application. Engine design features and basic history of the design will be reviewed.

4.1. SATURN BOOSTER ENGINE (H-1)

The Saturn project was initially conceived by the Army Ballistic Missile Agency in 1957 as one of a family of space vehicles. The Saturn vehicle called for a high thrust clustered engine system for the booster stage providing 1,500,000 lb. thrust. Preliminary studies were conducted to analyse engine clustering for this application. These studies indicated that the clustering technique was an excellent method of quickly attaining a high thrust propulsion system.

Early in the autumn of 1958, the concept of utilising a cluster of eight 188,000 lb. thrust (H-1) engines was adopted for the Saturn booster stage. This engine system required minimum additional development for a cluster application. Therefore, a reliable engine cluster, although requiring more engine units, could be available sooner and would cost less than any other booster stage propulsion system. The initial contract to provide eight R and D engines for ABMA cluster tests was negotiated in August 1958.

The H-1 engine is an outgrowth of the engine systems used in the Thor and Jupiter IRBM. The engine, Fig. 13, has a bell-type, regeneratively cooled, tubular wall thrust chamber, operating with liquid oxygen and kerosine propellants and was designed to develop 188,000 lb. of thrust. Gimbaling of the entire engine package is facilitated through the use of flex lines in the low-pressure propellant ducts connecting the vehicle tanks to the turbo-pump inlets.

The H-1 engines for the Saturn differ slightly in their design, depending on their intended placement in the cluster. The four outboard engines are gimbaled to provide thrust vector control for the vehicle. The four inboard engines are mounted fixed.

Inherent in the H-1 engine is the feature of independent engine design. Each engine in the cluster operates independently of the others. The engines are connected only through electrical impulses that control startup and shutdown. This feature allows each engine to be a complete package.

The H-1 engine also incorporates new features proved in the Rocketdyne experimental test engines: a simplified control system and advanced engine fabrication concepts. Engine operation is controlled by a pressure ladder sequence which eliminates virtually all electrical, hydraulic, and mechanical equipment formerly required for engine operation and control. An electrically actuated solid propellant turbine starter initiates engine operation. Main chamber ignition is obtained by a hypergolic slug. Cut-off of the engine is accomplished by an explosively operated valve. Thus, although start and stop are accomplished by electrical signals, no electrical devices control engine operation.

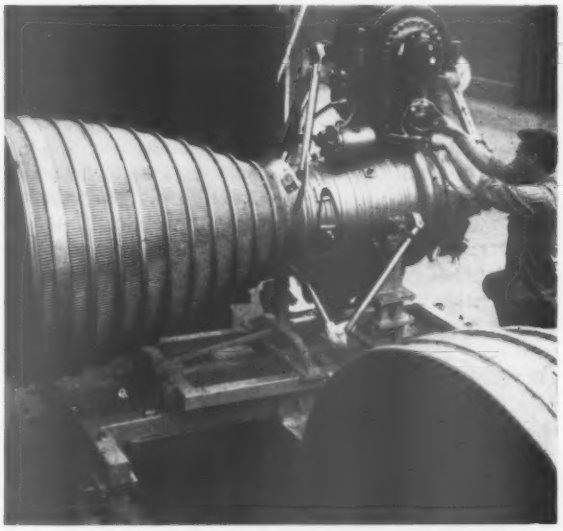


FIGURE 13. This completed H-1 engine will be used in a cluster of eight to provide 1,500,000 lb. thrust for the Saturn booster. The H-1 illustrates the simplified design typical of advanced engine systems.

4.2. 400,000 LB. THRUST ENGINE (E-1)

Because of the ever-increasing requirement for higher thrust, considerable interest was expressed in a single rocket engine capable of thrust levels previously possible only with clusters of smaller engines. In 1956 the first 300,000 lb. thrust chamber assembly was built and tested, and in late 1958, the first E-1 engine was assembled and subsequently test fired. Later efforts on the engine have included tests in the 400,000 to 500,000 lb. thrust class.

The highest thrust currently achieved with storable propellant combinations has been with the E-1 thrust chamber assembly. With this component, tests have been conducted with the storable nitrogen tetroxide/unsymmetrical dimethylhydrazine (NTO/UDMH) combination up to 300,000 lb. of thrust. This engine has supplied a fund of experience for development of the 1,500,000 lb. thrust (F-1) engine. It was especially useful in solving problems of priming, combustion stability, and fabrication of large engines.

4.3. 1,500,000 LB. THRUST ENGINE (F-1)

The F-1 engine, designed to produce 1,500,000 lb. of thrust, is the largest single-thrust-chamber engine known to be under development. A contract to design and develop this engine system was received from the National Aeronautics and Space Administration in January 1959. In August 1959, eight months later, mainstage testing demonstrating stable combustion was performed. Many additional start and mainstage tests have since been conducted on the thrust chamber. The engine is in the design and development stage and the

complete flight-rated system will be available in the early 1960s.

The F-1 engine is designed for operation with liquid oxygen/kerosine propellants. The engine incorporates many "test-proved" advanced features. This use of previously proven features provides engine delivery in the shortest possible time. The engine uses a conventional bell-shaped nozzle design, if a nozzle as large as shown in the model, Fig. 14, can be called conventional. It has regeneratively cooled tubular walls. The turbo-pump is side-mounted on the thrust chamber and the entire unit can be gimbaled.

In a single engine application, the F-1 will provide the maximum performance and ultimate reliability for an advanced second-generation space booster. In a clustered engine application the F-1 fulfils the need for a highly reliable clusterable engine.

A large space vehicle might use four or six F-1 engines for the booster stage, and have two, three or four liquid oxygen/liquid hydrogen upper stages, depending on the mission. With a four-engine booster, a two-stage vehicle is capable of placing up to 270,000 lb. in an earth satellite orbit, while a four-stage vehicle could place up to 90,000 lb. in a stationary "24-hour" orbit, soft-land 50,000 lb. on the moon, or place 60,000 lb. in a Mars reconnaissance orbit.

4.4. LIQUID OXYGEN/LIQUID HYDROGEN ENGINE (J-2)

Early in 1959, several rocket engine and vehicle manufacturers were asked by the National Aeronautics and Space Administration to investigate the design requirements for a high thrust, high energy propellant, upper-stage engine system. The upper-stage engine system investigation was based on the use of liquid oxygen/kerosine boosters having thrusts of 1,500,000 and 6,000,000 lb. The results indicated that the use of a liquid oxygen/liquid hydrogen propellant engine rather than a liquid oxygen/kerosine propellant engine in the second stage would result in up to an 80 per cent gain in payload capability for an earth satellite mission. For an extended space mission, such as a Mars orbit, similar high gains in payload capability were indicated.

On 1st June 1960 the N.A.S.A. contracted for the design and development of a 200,000 lb. thrust class liquid oxygen/liquid hydrogen propellant engine system. First use of this engine is anticipated to be in an upper stage for the Saturn project.

This engine system is designed for high altitude operation; the engine features advanced concepts tested and proven in the experimental engine test programme. The thrust chamber design is based on thrust chamber tests conducted at Rocketdyne's Propulsion Field Laboratory. These tests demonstrated high propellant performance and stable combustion. A test firing of a 200,000 lb. thrust liquid oxygen/liquid hydrogen thrust chamber is shown in Fig. 15. The gas generator design is based on previously tested full-scale models. The design of the hydrogen pump has been enhanced by previous programmes conducted to investigate hydrogen pumping.

In the design of the J-2 engine, high reliability is an engine requirement and thus a primary development criterion. A rigorous and comprehensive reliability programme is integrated in every phase of the engine development, from basic design to delivery of the developed system. The J-2 engine development programme is directed toward completion of preliminary flight rating tests and qualification by the mid-1960s.

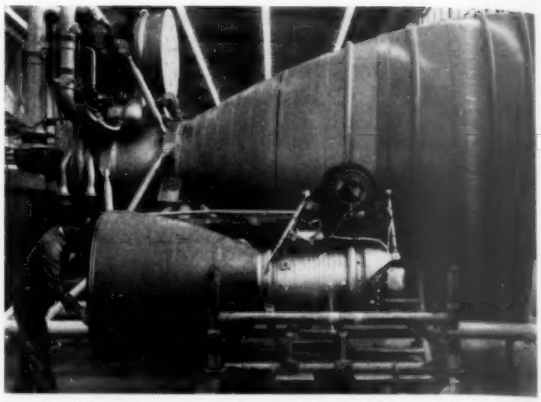


FIGURE 14. Full-scale mock-up of the 1,500,000 lb. thrust F-1 engine. The H-1 engine shown in the foreground illustrates the size of the new engine.

5. The Next Decade

The review of the progress of large, liquid-propellant rocket engines during the past ten years shows extensive advancement in every phase of their design. From the 75,000 lb. thrust engine developed for the Navaho and subsequently used on the Redstone, to the simplified H-1 for the Saturn, the advanced 1,500,000 lb. thrust F-1, and the high-energy propellant J-2, the keynote has been increased reliability and simplicity, together with higher thrust, higher performance and reduced weight.

The new, advanced, liquid-propellant powered systems, utilising liquid oxygen/kerosine for booster engines and high energy liquid oxygen/liquid hydrogen for upper stage engines will supplement the present Thor,

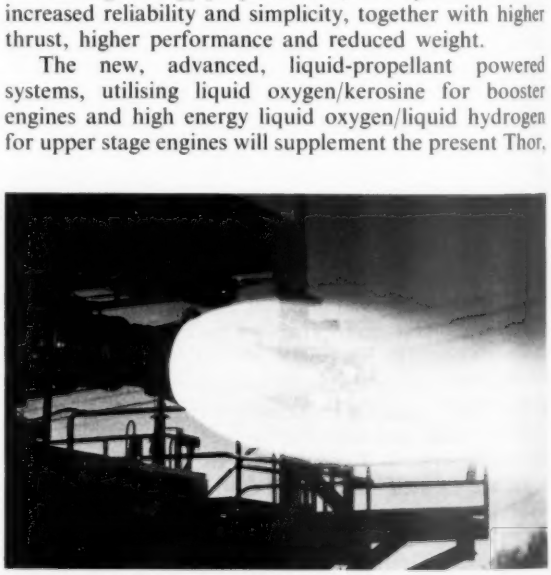


FIGURE 15. Liquid oxygen/liquid hydrogen thrust chamber test. Stable combustion has been demonstrated with the high energy combination, liquid oxygen/liquid hydrogen, at high thrust levels.

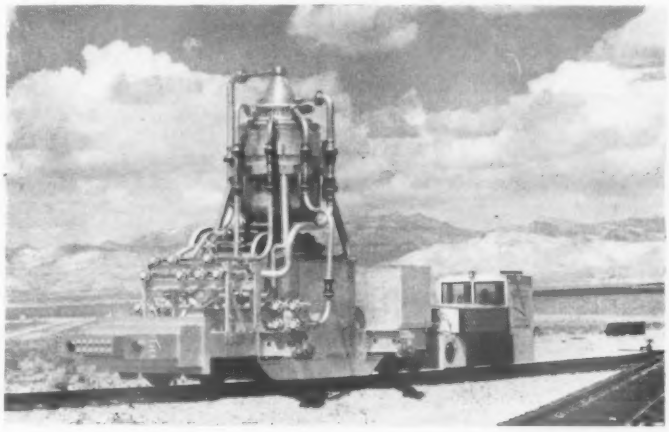


FIGURE 16. Kiwi-A nuclear rocket engine. The initial test of a nuclear rocket engine, the Kiwi-A, was conducted in July 1959 at the Nevada Test Site.

Jupiter and Atlas vehicles for many future space flights. These liquid-propellant rocket engines will continue to be the workhorse systems for space flight in the coming years.

The demands in booster thrust capabilities and high performance that will exist for future space missions during the next decade will require many further advances in engine design. Studies of future rocket engine requirements have indicated the need for higher thrust and higher performance. A chronological review of rocket engines historically bears out these requirements.

A new, high thrust, liquid propellant rocket engine that has a high performance potential is the nuclear engine. The high thrust and high performance which it can attain will make it attractive for many advanced space applications.

In the nuclear engine, a specially designed reactor heats a single propellant to a high temperature gaseous state. A low molecular weight propellant results in a high exhaust velocity and thus high performance. Hydrogen, with a molecular weight of two, is an attractive propellant for the nuclear engine. For example, the maximum specific impulse, the common basis for comparing engine performance, obtainable with chemical propellants is somewhat greater than 400 seconds. With the nuclear systems, specific impulse values two to three times greater are possible.

Although the ultimate pay-off of nuclear rocketry lies in the all-nuclear vehicle, the development time and the cost required for a nuclear booster indicates that this vehicle probably should be preceded by lower thrust nuclear engines in upper-stage applications. This system, while not achieving the ultimate attainable performance of the all-nuclear system, provides a high performance gain over upper stages with chemical engines.

The use of the nuclear engine in an upper stage eliminates the operation of the "hot" nuclear reactor at the launch facility. The Saturn vehicle with a nuclear engine third stage replacing the single 200,000 lb. thrust liquid oxygen/liquid hydrogen (J-2) engine can soft-land a 14,000 lb. payload on the moon compared to 6,000 lb. with the J-2 third stage. The use of hydrogen propellant in space has been thoroughly investigated and the storage of hydrogen in a space stage for an extended time is feasible through the use of multi-layered reflective radiation shields

In August 1957, Rocketdyne was awarded a contract to manufacture the test nozzle for use in the Kiwi-A, the first reactor designed to study the feasibility of nuclear rocket propulsion. The reactor, developed by the Los Alamos Scientific Laboratory, and the nozzle were successfully tested at the Nevada Test Site (Fig. 16) in July 1959. In addition, substantial progress in the design of nuclear engine components has been accomplished.

In the past, new designs for rocket vehicles were based on a chemical propellant engine system. The state of nuclear engine design technology did not permit the consideration of a nuclear engine for new applications. The extensive work on nuclear engine systems has now provided a wide background of technical information. Design concepts investigated have proved to be practical and applicable to a flyable engine design. Although additional work is required, nuclear engine technology is at the point where development of a safe, reliable nuclear rocket engine can begin. It is clear that in the next decade the nuclear engine will be developed to provide the power and performance required for our advanced flights into space.

In the next decade we shall also see the development and employment of recovery systems for rocket vehicles. At the present, parachute, winged-glide and turbo jet concepts are being investigated. The ultimate recovery system will see an intact fly-back and set-down of the complete stage. Regardless of the actual recovery method, the liquid-propellant rocket engine is best suited for this application. The design life may be virtually unlimited, and a rocket vehicle stage with a liquid-propellant engine is ready for re-use by simply refilling the propellant tanks. With the development of the recovery system, operating costs for space flight will be reduced; and the reusable liquid-propellant rocket engine, chemical or nuclear, will be without equal in space vehicle applications.

The First 25 Years of the Bristol Engine Department*

BY

SIR ROY FEDDEN, M.B.E., D.Sc., Hon.F.R.Ae.S., Hon.F.I.A.S.

From Sir Reginald Verdon Smith, Hon.LL.D., M.A.:—

Sir Roy Fedden's Barnwell Memorial Lecture for 1960 is a notable addition to aviation history, all the more valuable for being written by the man who was himself primarily responsible for the achievements which he describes. This lecture, by spanning the whole period of Bristol aero-engine development from its origins at Brazil Straker's in the First World War up to the ultimate development of the sleeve valve radial by the time of the Second World War, and by the method in which it has been presented, carries with it a sense of unity and of perspective which is unusual in any history of recent events. Not only does it narrate the individual successes and disappointments of twenty-five years, but it also displays for the contemporary reader a phase of aero-engine development in which determination and resourcefulness nearly always counted for more than numerical strength and complex equipment. It is characteristic of Sir Roy Fedden that he is the first to acknowledge and to repeat throughout his lecture that his particular success lay in the way in which he gathered round him a group of able men both in the design department and in the works. His narrative demonstrates vividly how they responded whole-heartedly to his enthusiasm, welcomed his energy and drive, and shared with him the long hard road of development which is the essential key to engineering achievement.

I am particularly glad to have been invited by Sir Roy to contribute this foreword and thus to have an opportunity on behalf of the Bristol Aeroplane Company Ltd. of repeating in THE JOURNAL the whole-hearted acknowledgment which I paid to Sir Roy's work when the Lecture was first delivered to the Bristol Branch of the Society.

Introduction

Few things have given me greater satisfaction than the invitation to give the Seventh Barnwell Memorial Lecture, and tell the story of the early history of the Bristol Engine Department.

The Bristol Aeroplane Company which was founded by that great merchant venturer and pioneer of transport, Sir George White, has just passed its 50th Anniversary. I always look upon the 20 odd years spent with the Bristol Company as among some of the happiest and most stimulating in my engineering career.

I was first in touch with Barnwell in 1917 when he was instrumental in arranging for me to have my first flight. This was in a Bristol Fighter fitted with a Rolls-Royce Falcon engine and my firm, Straker's, had been responsible for the manufacture of the engine. Later the Air Board arranged for Straker's first 14-cylinder Mercury Engine to be fitted into his Bristol Scout F Type 21, which at the time was awaiting an engine. He was friendly and courteous during this installation work on our entirely unknown and untried engine.

Three years later in 1920, when I joined Bristol's and started talks with him on the installation of our Jupiter in the Bristol Badger, which was awaiting a Dragonfly engine, I was obviously the novice hoping to win out in the engine field, but conscious I was dealing with the proven designer of the renowned Bristol Fighter and Bristol Monoplane.

During all my subsequent negotiations and meetings with Frank Barnwell, I always found him helpful and considerate. His understatement, modesty and diffidence about his accomplishments, which qualities were so attractive, were carried almost to a fault by him.

Walter Tye in his Barnwell Memorial Lecture dealt at length with the subject of metal fatigue in Aircraft Structures, and described the great effort that had been put into curing this serious problem since the Second World War. This is particularly significant, because the question of fatigue in aero-engine components, the cause of fatigue in service, and how these were eliminated, were among the most important subjects that were successfully tackled by the Bristol Engine Department during the first few years of its life—some 30 years before the Comet enquiry which, in the minds of many of the aircraft fraternity, was the first time anything had really been known about fatigue.

Our Material Laboratory and Fatigue Testing Equipment were looked upon as rather a luxury. In fact I believe most aircraft designers were at this period unresponsive to the significance of such facilities, and were unconscious of the benefits that could be obtained from the knowledge and experience gathered by the Engine people who had been able to bring metal fatigue under control. This outlook lasted up to the time of the Second World War.

Thinking over what to say in this Lecture to make it authentic, and to give as true a picture as possible of what we concentrated upon first, I have come to the conclusion that the success of any aircraft venture is as often as not balanced on a knife edge. Looking back on the early days of the Engine Department, I have realised how tremendously important certain steps were, either to advance our project or, on the other hand, to bring about the reverse effect, the significance of which did not become evident until some years later.

*The Seventh Barnwell Memorial Lecture—given before the Bristol Branch of the Society on 10th March 1960.

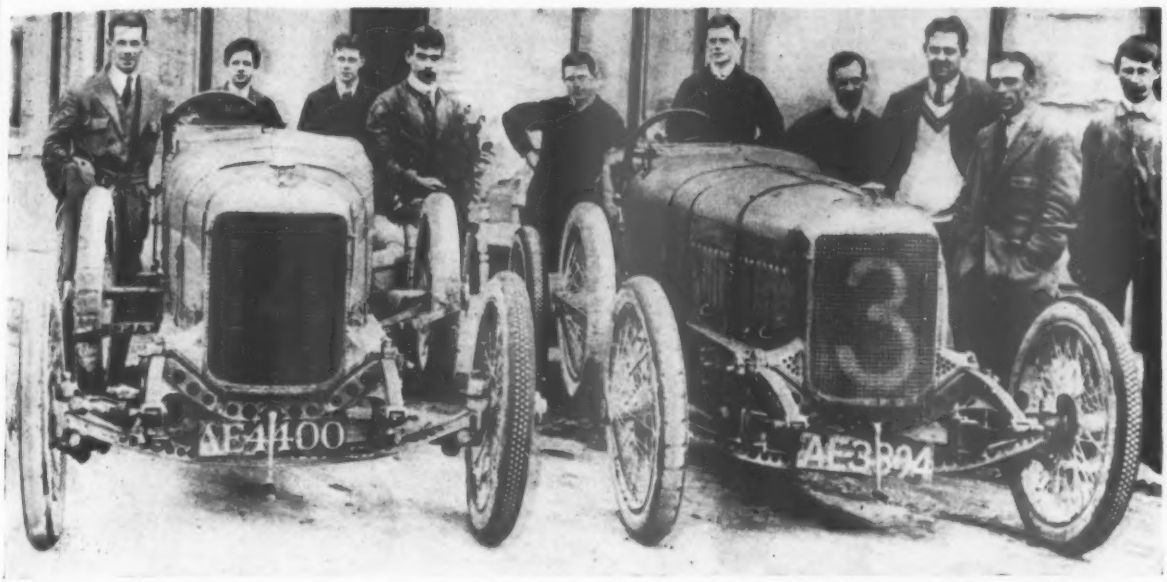


FIGURE 1. Straker Tourist Trophy Team, Isle of Man, June 1914. Unfortunately it has not been possible to name all the team, but the group includes, from *left to right*, F. C. Clement (driver), E. Winstone, Preston (fourth from left), Rudman, and starting fourth from the right, Brown, A. H. R. Fedden, R. S. Witchell (driver) and Wiltshire.

I think it worth underlining this point, since if such an approach held good 35 years ago, I suggest it is even more the case today when the whole tempo and technique are so much more intensive.

Before describing the early activities of the Bristol Engine Department, I must recount why it was initiated at such a difficult period, and what sort of people formed the nucleus of this new organisation.

We had been working for a number of years at an engineering plant situated at Fishponds, a suburb of the city of Bristol about 5 miles from Filton. We had all come up the hard way, and had had a varied, general engineering experience. We came from one division of a well-known Bristol engineering group called Brazil Straker, which before the war had three different plants at St. Philips Marsh in the city of Bristol, as well as the new factory at Fishponds. The group manufactured steam wagons and motorbuses, the latter including most of those on the London streets before the First War, a fair number being exported also; a successful line of cigarette-making machinery; and a wide range of marine engines from 10 h.p. up to 250 h.p. There was also a large iron and bronze foundry with comprehensive pattern shop, and we produced a 15 h.p. Touring car.

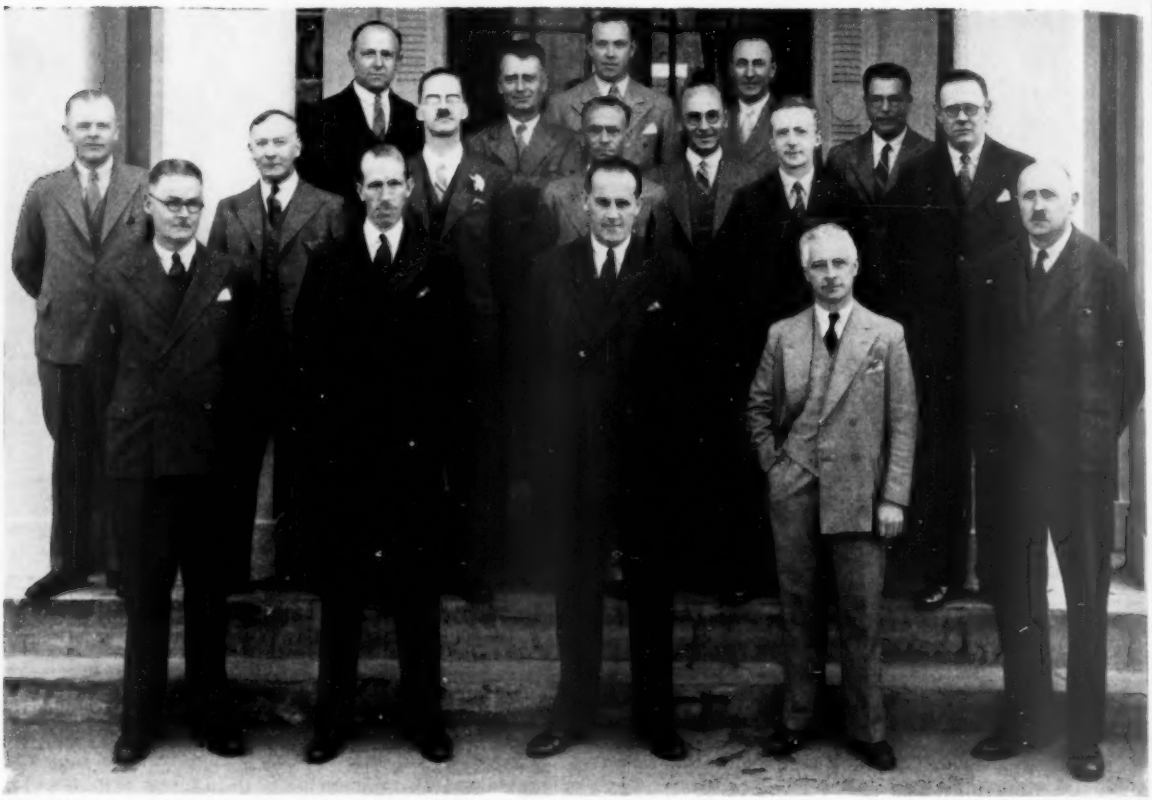
I was stationed at the Vehicle works at Fishponds, and was responsible for putting up a car design and persuading Mr. J. P. Brazil, the Managing Director, to enter the touring car field. We exhibited our first car at Olympia in the Autumn of 1907. It proved successful both commercially and in competitions, and we concentrated for the next seven years on one model, a 15 h.p. car, endeavouring with some success, to put the highest quality of workmanship into it. Our highest output was just over 500 cars in one year.

Shortly before the First World War a few of us became interested in aero-engines. We took every opportunity either to attend or learn what was going on in motor car racing and aeroplane trials both in Great Britain and on the Continent. I visited the 1914 Naval and Military aero-engine trials, which were won by an Argyll Burt-McCollum single sleeve valve engine. This made a deep impression upon me at the time. I also paid two trips to France with Mr. Brazil with the idea of acquiring the rights to manufacture an aero-engine.

Through contacts with the head of the R.N.A.S. Aero Engine Division (the offices of which were situated over the Admiralty Arch), we had our initiation into aero-engines at Fishponds early in 1915.

We first undertook the overhaul, minor re-design work, and testing of a number of American-made Curtiss OX 90 b.h.p. engines built for the R.N.A.S. Later we manufactured completely, Rolls-Royce Hawk 6-cylinder 100 b.h.p. engines, and Falcon 12-cylinder 280 b.h.p. engines, as well as producing a number of parts for Derby for the Eagle 12-cylinder 360 b.h.p. engine. We also manufactured a number of V.8, 80 b.h.p. Renault engines. During the War we manufactured just over 1,500 complete engines, as well as a number of parts and spares, and at our peak employed about 2,000 workpeople.

At the beginning of 1917 we entered for a Naval competition initiated by Admiral Murray-Sueter, for an air-cooled engine with a diameter not greater than 42 in., to weigh not more than 600 lb. and to develop 300 h.p. We designed an engine of 1,250 cubic inches, built it and had it running in 5½ months; there were a number of other entries and we were successful jointly with the Siddeley-Deasey Company in receiving production orders, but our order for 200 engines was cancelled a few



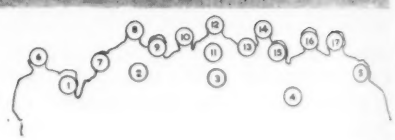


FIGURE 2. A group of seventeen of the original thirty-one people who came from Fishponds to start the Bristol Engine Department in August 1920:—(1) R. N. Swinchatt, (2) R. Stammers, (3) A. H. R. Fedden, (4) L. F. G. Butler, (5) H. V. O'Gorman, (6) W. Jefferies, (7) B. Brown, (8) S. Damsell, (9) F. Powell, (10) H. Wills, (11) R. Williams, (12) G. J. Gulliford, (13) A. J. Cox, (14) A. G. Adams, (15) G. Bennett, (16) A. Houlson, and (17) F. Collett.

months after the Armistice. The Siddeley order was retained, and the engine became known as the Jaguar.

(To digress a moment from this early history, for the first few years of the Bristol Engine Department, the Siddeley Company were our greatest rivals under the leadership of Major Green. We had been handicapped by a period of enforced idleness when the Cosmos Company which had acquired Straker's, shut down, which gave Siddeley's a good lead over us. After a number of years, however, chiefly due, I believe, to our realistic overload Engine Test Bed development and long series of endurance flight testing, we gradually drew ahead. The wheel has turned full circle and today Bristol and Siddeley interests are linked into one organisation.)

We followed up the Mercury by a larger engine called the Jupiter of 1,750 cu. in., a 9-cylinder radial which we had running towards the end of 1918. The first engine ran well, weighed 662 lb. or 1·4 lb. per b.h.p. and had a specific fuel consumption of 0·565 pints/b.h.p./hour. I believe this was the lightest aero-engine of its day.

In December 1918 I had two important letters from Brigadier General J. G. Weir, Technical Controller of the Ministry of Munitions, about going on with the Jupiter. I will quote from one which read as follows:—"With reference to your Aero-Engine work, I wish to impress upon you that the changed conditions due to the Armistice do not affect the importance of your Experimental and Development work in connection with engines, and it is most desirable that you should continue with your efforts in this direction. It is of very great importance to the Nation, as far as Aircraft is concerned, that you should press on in all haste to perfect the Jupiter which I feel sure has a considerable future in front of it for Commercial Aviation."

An inspiring letter for a young team and it helped us greatly to weather the storm that came to us later on.

At the end of the War, the various activities of the Brazil Straker Group were sold to other companies, the aero-engine business, together with an original 3-cylinder, air-cooled radial car with coil suspension front and rear, going to a new group called Cosmos that had large coal and shipping interests mostly in South Wales. This new Company acquired the Fishponds works, which had modern machine shops, extensive heat-treatment and general equipment and, what was in those days a good experimental department and test plant.

Within two years the Cosmos Company went into liquidation. I was appointed by the Official Receiver to dispose of the aero-engine goodwill and got three firms interested—Bristol, Siddeley, and Vickers.

As the months dragged on, and neither of the three made a decision, I decided that it might help matters to undertake a Type Test of the Jupiter under official A.I.D. supervision. I therefore obtained permission to embark on this test and completed more than half of it successfully, but when the Official Receiver in London saw the account from the Bristol Corporation Electricity Department for the current for the cooling fan, we were not permitted to finish it.

I still remember my last interview with Vickers when General Caddell, head of the Weybridge Aircraft Works, told me that he would have much liked us to join him, but felt it was too much of a gamble to marry an engine and airframe firm together.

Eventually satisfactory terms were fixed with the Bristol Company and for the sum of £15,000 they acquired the goodwill of our engine business, all drawings, patterns, jigs and tools, five engines more or less in running order, a number of finished parts, and the best part of 50 sets of Jupiter raw material.

July 1920 was an important month for those of us at the Fishponds factory impatiently waiting to start up our engine business again. During the second week, the S.B.A.C. held its first Aircraft Exhibition at Olympia and to everyone's surprise the Bristol Company had an Engine Stand alongside their Aircraft Exhibits, showing the Cosmos range of engines. This was the first official announcement that Bristol's had acquired the Cosmos radial engine business, a striking tribute to the enterprise of the Bristol Board. On 24th July, Cyril Uwins piloted the Bristol Bullet with the Cosmos Jupiter engine into third position in the Aerial Derby. The previous year he made the first flight on the Scout F successfully, with the original Cosmos Mercury engine and from then onwards was responsible for the flight testing of all Bristol Engines over this first 25-year period.

The First Ten Years of Bristol Engines

The Bristol Engine Department was officially founded on 29th July 1920. During the first week of August a nucleus of 31, consisting of a few carefully selected staff, draughtsmen, technicians, and workmen, came over to Patchway aerodrome to start up the Department.

In my position as representative of the Official Receiver of Cosmos, the Bristol Director with whom I had to deal was the late Sir Henry White-Smith, and it was he who personally gave us our official start with the Bristol Company. When we arrived at Patchway the people with whom we were most closely associated in the early days were Herbert Thomas, Stanley Daniel and Gavin Greig, the reserved but tough Scottish Secretary of the Company. These three played a considerable part in helping us to establish the Engine Department. We were directed to take all our equipment and belongings to Patchway aerodrome, select what buildings we thought would be necessary, put in estimates for our requirements and then get going as quickly as possible.

The burden of making these decisions fell upon me, with the help of Leonard Butler who was in charge of our design team, Bill Stammers who looked after our office side and buying, and acted in a liaison capacity with Filton House, and O'Gorman our Chief Machine Shop Foreman. Butler had come to Fishponds from St. Philips Works some years before to help on car design, and on the resignation of our Scottish Chief Draughtsman, had succeeded him. He had developed considerably during the war years and was remarkably ingenious in mechanical design and particularly good at attention to detail. In my opinion his influence in these directions played a great part in our ultimate success.

The building we decided should be our Machine Shop is now known as the Development Power Plant Dept. (D.P.P.D.). In it we found parts of a derelict Porte Flying Boat which we duly took over to the wasteland on the other side of the aerodrome and burned. In another shed we were surprised to find a remarkable collection of foreign aero-engines, consisting of a variety of Gnôme, Clerget and other rotary, air-cooled types, one or two Anzani static radials, a flat-four Darracq water-cooled engine, and some Salmson water-cooled radials. Secretly we wondered what the Bristol Company wanted us for! Having taken all the relevant data we wanted from them, we decided that the best thing was to get them out of the way as soon as possible.

Although we started with only empty buildings of a not very suitable nature, it all turned out to be great fun because we were so glad to be busy again, and we were left alone to work out our own salvation. We started from nothing and at first had to make do on a shoestring, but at least there were no liabilities to absorb. An important quality for successful aeronautical work was that we had had good commercial experience in a hard school, and in consequence, possessed a sense of urgency. Anything we bought we knew full well we should be held responsible for, and therefore we took every precaution to make as sure as we could that it suited our purpose.

By the end of 1920 we had the shops fairly tidy, sufficient power laid on from the Bristol Corporation to run the machine tools and test plant brought over from Fishponds. The very fact that we were so comparatively inexperienced on aero-engine work, yet experienced on traditional engineering, and tremendously keen and confident, eventually proved to be our salvation.

Soon after the First World War, when I had decided to throw in my lot with air-cooled radial engines, I remember having a talk with Mr.—later Sir—Henry Royce, whom I had got to know as a result of his conferences at St. Margaret's Bay near Dover, on Rolls-Royce engine manufacture, when I had been in the habit of meeting him with either Messrs. Hives, Harvey-Bailey, or Elliot. He told me in a friendly way how unwise I was to think I could ever make a success of a big air-cooled radial engine and that he was surprised that I could be led astray in this way. At the time I did not tell him that one of the main reasons was that the Rolls-Royce solicitor, Mr. Claremount, had tied up Straker's so tightly in an agreement, that we could not make an in-line liquid-cooled engine of our own design. Nine years

later I had the pleasure of meeting Sir Henry Royce again and he was generous enough to congratulate me on the success of our engines, and to say that he was glad his advice had been proved wrong.

During those first tough years, I often remembered that advice of his and wondered whether I had backed the wrong horse. The results we eventually got were only made possible by the most devoted team, and by rejecting the word "can't," however black things looked at the time.

On the understanding that the Bristol Company bought the goodwill of Cosmos Engines and undertook their development, an order was received from the British Government in August 1920 to manufacture 10 Jupiter engines, including those that had been brought over from Fishponds, for the sum of £25,000. We also received an order for one engine from the American Government, the latter as a result of Major McCrindle, later a Director of B.O.A.C., whom Sir Henry White-Smith had sent out to America and who, incidentally, sent me back some excellent information.

I must admit that I worked my team very hard and impossibly long hours. They took most of it with good grace and remarkable loyalty because apparently they believed in my policy and carried out almost everything I wanted to do without question. Provided one is not hopelessly off the beam, anyone can work wonders with such backing as I had, but nevertheless what was accomplished in the first few years is surprising when I look back on the scene after such a lapse of time.

We soon found that our fifty sets of material, which had been passed by the A.I.D. but bought at a difficult time immediately after the war, were not much good and we had to throw nearly all of them away.

One of the first things I did was to call in Professor Aitchison who had been responsible for setting up the Materials Department at the Air Board, and who wrote a classic procedure for Aircraft material specifications and testing, which was undoubtedly ahead of anything else in the world at the time. He was a tower of strength to us and early on the Materials Laboratory was initiated. Material suppliers were tackled individually, generally by my going up with him to their works.

Long series of tests were embarked upon to eliminate stress-concentration and he made, with Butler and myself, a detailed investigation of the shape of all Jupiter components, leading to the recognition of the great dangers inherent in sharp corners, insufficient fillets, and in scratches, abrasions, etc. This led on to the general smoothing, polishing and protecting of all highly stressed parts. I learned from him the vagueness of contemporary thought on this whole subject, discernible in the common attribution of failure by fatigue to "crystallisation," an entirely arbitrary affliction against which engineers could do nothing, except keep their fingers crossed. He also taught us that for virtually all the aeronautical steels of that time, the fatigue limit of each was just under 50 per cent of the ultimate strength, which enabled us to think of fatigue for the first time in quantitative terms.

A year or two later he allowed me to have his assistant Leslie Johnson, who after working at Bristol for many years went on to Mond Nickel to achieve a high reputation there. This foundation work has been ably carried on by Jim Gadd and his team, whom I believe are still doing pioneering work in the material field.

The early setting up of a sound Design Office organisation and procedure for the adoption of special standards of detail were instituted. There was an early insistence on drawing standards and these had a great bearing on the successful licensee business and the prompt way in which the Shadow Engine Industry was organised just before the Second World War.

At an early date, inspection was placed on a thoroughly sound footing, adequately staffed and backed up by first-class equipment, technical records and test plant. A Quality Control Manager was appointed and a Model or Specimen Room set up as an adjunct to, but not part of, routine inspection (not a generally accepted practice in those days), together with the development of detailed workshop and inspection instructions, which became a major function of the Inspection Department.

The importance of a well-integrated, sympathetic hard core to the executive team with close accord between Design and Shops was realised. In the early years of the Butler-Whitehead era these two key men personally vetted the first-off of all new components. Realistic tolerances, a vital factor in the success of the engine as it developed in rating, and the rapid transference of "know-how" to the licensees through the Licence Office, were put into effect.

Provision was made for the design, acquisition and sometimes the manufacture of specialised plant, also for Laboratory, Main Engine Test, Research and Instrumentation Departments, covering such items as the Bristol/NPL combined stress fatigue testing machine, creep testing machines, the original, completely enclosed and silenced test beds, con-rod and big-end bush test rigs.

A Flight Test, Installation, and Service Department built up early on by Freddie Mayer, I have little hesitation in saying was more efficient than any other aero-engine maker or Government Department of that era. He had a great knack of training and bringing on good mechanics, getting on well with Management in the aircraft factories and promptly bringing back to the Works sound information and reports on how our engines performed.

When we started to licence other countries to make our engines, we fortunately appreciated the importance of sending out properly trained representatives who were resident in the countries concerned, sometimes for many years. This policy paid handsome dividends and men such as Norman Rowbotham, Roger Ninnes, Bert Newport, Jim Gadd, and Burgoine to mention only a few, were among the many who, by their special knowledge and enthusiasm, made it possible to spread the doctrine of Bristol engines so remarkably quickly all over the world.

Regular visits were paid by me with Freddie Mayer and Frank Abell to Aircraft Works to investigate installation problems on the spot, deal with complaints and discuss new types.

Although the things that we did in those early days (over 30 years ago), may seem elementary and commonplace now, almost every step of the way we were pioneering; we were breaking new ground and tackling basic

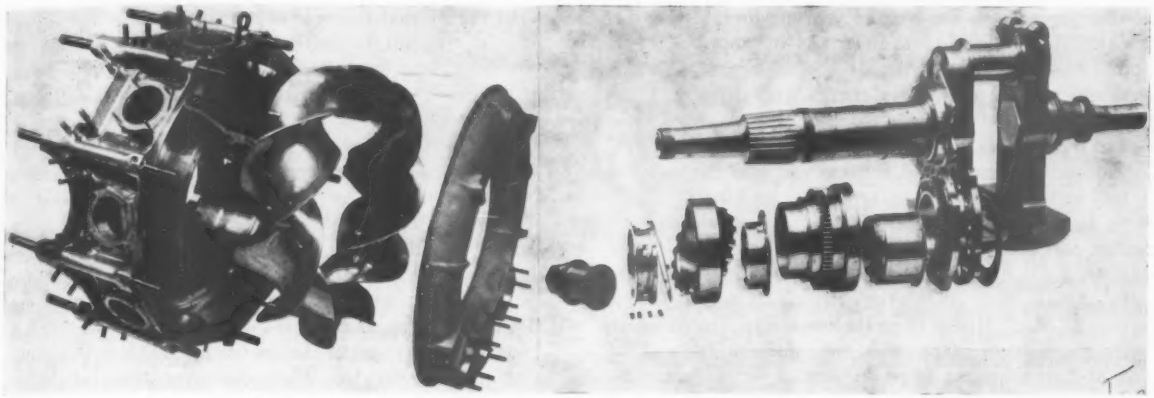


FIGURE 3. Jupiter forged crankcase with induction spiral and crankshaft, showing valve timing gear.

matters nearly all the time. For example, having failed to get anything but porous cylinder head castings from several firms in the Midlands, we set up a foundry on waste land at the back of the aerodrome and got a good supply of satisfactory castings within three months.

The extremely small size of the Engine Design and Development team (under 50) of the first decade as compared with other firms at that time, together with its close personal touch, loyalty, and integrity should be emphasised. It is worth noting that A. C. Lovesey in his Third Memorial Lecture commented on the slowing up in technical achievement today in spite of Rolls-Royce's present technical capacity being 50 per cent greater than in 1939.

Bringing the Engine Department over to Patchway Aerodrome enabled us to develop an entirely new approach to engine testing, both on the ground and in the air. Our test plant was improved and added to, and laid out right on the edge of the aerodrome. In personal contacts with Cyril Uwins and his test pilots we learned a great deal more about flight testing and the working conditions of our engines in the air, and they were readily able to see how our engines were tested on the ground. This combination proved to be of the utmost value and we got through very quickly a great deal more testing both on the bench and in the air than ever before, and learnt much thereby.

At the end of the first week in September 1921, we completed our first official type test, the first British engine to pass the new A.I.D. postwar Type Test Schedule.

Shortly after this memorable day, the Bristol Board told me that although they appreciated that the team had worked hard, apart from their initial expenditure to acquire the design and goodwill of our engines, a total of nearly £200,000 further had been spent in all on the Engine Department over the past 15 months and we had sold only eleven engines of which we had delivered two. There seemed no prospect of any more orders at the moment; I could do anything I liked within reason in the meantime to improve matters, but unless I had changed the order book position by the end of the year, their present intention was to shut the Engine Department down. There was nothing to do but to accept this, but I asked that we should have one more chance and be allowed to take the Jupiter to the Paris Show. Permission was granted, and Bob Williams and his staff worked practically day and night to get the exhibits ready in time. We had a most effective stand, and the Jupiter stole the Show, and was a signal success. Traditional aero-engine makers had done practically nothing new, and exhibited their wartime products, while we offered a new design with a power-to-weight ratio a good deal better than anybody else.

To cut a long story short, the famous French Gnôme–Rhône Company decided during the Paris Salon to acquire a Bristol engine licence and this eventually proved to be the turning point in our history, although we still had to pass the official French type test and get the engine accepted by the Section Technique. This entailed a good deal of hard work, cheerfully undertaken by Swinchatt who received considerable help during the tests in Paris from Ken Bartlett who was then in charge of the Gnôme–Rhône motor cycle department. I had to spend a good deal of time over there also and all the tests were not completed until the end of June 1922.

However, our troubles were not by any means over and apart from an individual order here and there and a few demonstration engines, we were not successful in getting the British Government to give us a proper production order. A tremendous amount of interest in the engines, however, was displayed from all over the world, and in consequence the Directors did not shut down the Department but stuck to their guns with the Air Ministry. At last we received an order for 81 Jupiter engines. From then onwards, in spite of many difficulties, the Engine Department never looked back.

During the early years of the Department a number of important events happened to us. Fred Whitehead, who had been with me at Fishponds, had left before the war to join Vickers Crayford. He had been outstandingly successful, and developed greatly on munition tooling and jigging. In my search to get more staff, I wrote and asked him for help, and to my surprise and joy he said he would come himself; Leonard Lord (now Sir Leonard, head of B.M.C.) and he were, in my view, the two leading young men of the First World War on modern machining techniques, and I was most fortunate in getting him. The

part he played over the next 15 years in building up our machine shops, using great ingenuity by improvising on second-hand machine tools for special operations, and generally putting enormous energy and drive into the engine production was incalculable, and played a great part in our success.

Another piece of good fortune was that the wartime factory at Bookham, where the American Liberty engine parts had been manufactured and the engines overhauled, ran out of work entirely and they were able to take on a lot of intricate machining for us. A further lucky break was that the British Gnôme–Rhône factory at Black Horse Lane (belonging to Airco) which had a magnificent plant, went into liquidation, and we were able to acquire a large number of suitable machine tools at extremely favourable prices.

The early twenties was a vintage period at the Royal Aircraft Establishment on engines. Led by Major Norman, an experienced Engineer, a virile team of enthusiasts including Jock Taylor, Jimmy Ellor, B. C. Carter, and "Snowball" Taylor to mention only a few, were doing fine work on Engine Research and Development. Major Norman was most helpful to me in the early days of the Bristol Engine Department, and his sudden death was a serious loss to the Country.

I was successful in getting the Bristol Board to establish an Apprentice Department, and put in charge one of our old Fishponds craftsmen as Apprentice Supervisor. This proved to be an invaluable move as we were able to recruit a considerable number of keen young fellows from the Bristol area who in after years became the backbone of our skilled staff and we should not have been able to build up quickly enough without them. Bristol Engine apprentices established a high reputation, and were eagerly sought after by other firms. Several of them have done very well, including Cyril Luby who is now Managing Director of Dowty-Rotol, Walter Gibb now Chief Test Pilot of Bristol Aircraft and Charles Marchant now Assistant Chief Engineer of Bristol Siddeley Engines Ltd.

I shall never forget the extraordinary enthusiasm and interest of everybody concerned in our products, including the craftsmen on the Shop floor. I used to make a practice of endeavouring to go round the Drawing Office and the Works on alternate days. We always tried to let everybody know what we were after and when we had a special mission on hand. I seldom got far through the office or shops, before someone wanted to know what our chances were on a particular trial installation. Had our engine been successful, or had the Siddeley Jaguar, or the Rolls engine in some new type of machine won out?

I realise that this sort of approach and simple directness is difficult to foster with much larger staffs, the growth of the Trade Unions and the throttling effect of the Welfare State. We had an easier task in those days in some ways but we had our problems in other directions.

When we started at Patchway in 1920 we had two Mercury 14-cylinder engines built for the Government competition, one of which in the Scout F, flown by P. W. S. Bulman, then at Farnborough, climbed to 10,000 ft. in 5¼ minutes and did 143 m.p.h. at that height—both records which were to stand for seven years. There were also two ungeared and one geared Jupiter engines, and two 3-cylinder Lucifers of 100 h.p., plus a complete paper design for a 1,000 h.p. 18-cylinder engine. We decided, wisely however, that for the first years of our production life we would stick to the ungeared Jupiter and the 100 h.p. Lucifer trainer engine.

The Lucifer engine was robust and reliable, but was somewhat of a problem to the aircraft constructor from a torque reaction aspect. Barnwell's team made a most satisfactory installation job with a thick multi-ply bulkhead, which combination proved successful and was used for all initial training in the Company's School for the next 10 years. By the end of 1925 the Lucifer had gained a good record abroad, and was being used successfully in seven countries for training aircraft, 250 hours being the normal period between overhaul. At the end of this year the company completed a successful type test of the Lucifer at a rating of 123 b.h.p.

The first multi-engine installation was carried out at Filton in a wartime Handley Page 0/400. The performance was good and undoubtedly helped the Jupiter considerably, although I must admit we found a perfect spiral torsional fatigue failure in one crankshaft at the conclusion of the trials. A Bristol gas starter was fitted to this aircraft and was the prototype from which we received orders for several hundred.

The first British aeroplane to go into Squadron Service with the Jupiter engine was the Hawker Woodcock with helmet cowling. This was followed fairly quickly by the Gloster Gamecock, Westland Wapiti, Boulton Paul Sidestrand, and the Handley-Page Hinaidi Squadrons. The Vickers Vimy and Victoria were also improved and rejuvenated by re-engining with Jupiters.

We were unfortunate in not getting any Bristol machines into regular Squadron service in the first few

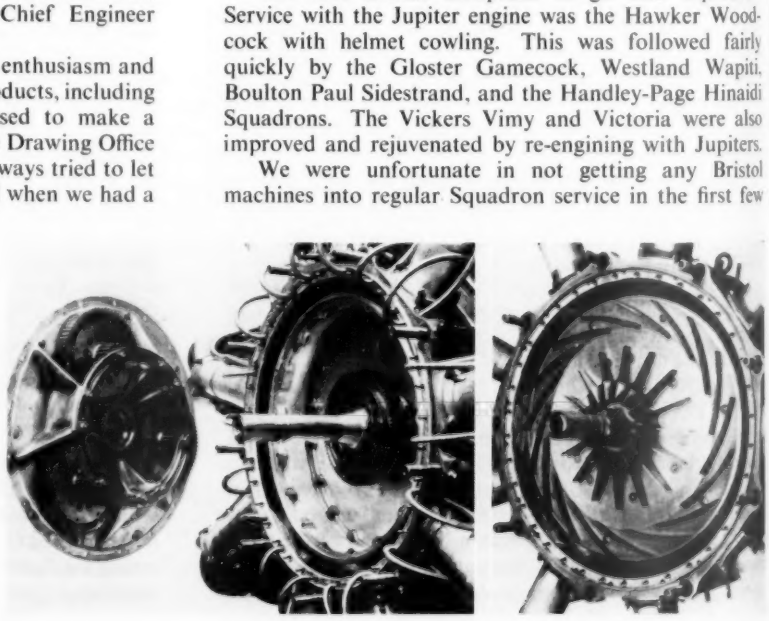


FIGURE 4. First Jupiter Supercharger, 1927. *In the centre*, the drive pinion mounted on the rear of the crankshaft with built-in spring drive; *left*, the double gear multiplier pinions, and *right*, the steel impeller with integral guide vanes.

FIGURE 5. Willie Messerschmitt standing beside his M.17 aircraft, with Bristol Cherub, 1928. At the time he was a comparatively unknown designer!

years, although Barnwell produced several promising designs, including the Bullfinch, Bloodhound, Boarhound, from which a great deal of useful installation experience was obtained.

In this early period, however, a considerable number of wartime Bristol Fighters were fitted with Jupiter engines and sold abroad, and were also used successfully in the Bristol Flying School for many years.

It was not until 1927 that the Bristol Bulldog first appeared, and eventually a total of 500 were ordered, including some two-seaters. During the first 10 years of the Engine Department, Bristol air-cooled radial engines were installed in 262 different prototype aircraft throughout the world, over 70 of which went into series production. Over this period the Gnôme–Rhône Company in Paris, with Norman Rowbotham as General Manager, were very active in manufacturing and pushing the Jupiter engine both in France and other European countries. Ken Bartlett who was with the Gnôme–Rhône Company when we initiated the Jupiter licence, joined Bristol's later and established an office in Paris, showing energy and initiative in selling Bristol engines abroad.

The Jupiter engine reached the height of its reputation towards the late twenties, when the well-known French daily *L'Aero* had two-inch headlines entitled "Scandale Jupiter" because nearly 80 per cent of the aircraft shown at the Paris Salon had Bristol Jupiter engines, a number of which were made in foreign countries under licence.

During the twenties we produced, type tested and developed three other engines of 5¾ in. bore, the same as the Jupiter, but differing in stroke and number of cylinders. These were: the three-cylinder Lucifer, which went into considerable series production, the five-cylinder Titan, and the seven-cylinder Neptune. The last two were type tested, and a few development engines made, but they were never tooled up.

In 1923, a Gourdou–Leseurre monoplane, in France, made a world record on a 50 kilometre closed circuit with the Jupiter at an average speed of 224 m.p.h. This aircraft had helmeted cowling and a retractable undercarriage. Four years later a racing float machine with helmeted cowling, designed by Carter and made by Short's, was entered for the Schneider Trophy race at Venice and exceeded 270 m.p.h. in practice flight. Unfortunately, the aircraft was improperly rigged after some adjustments (the aileron controls being crossed) and the machine was wrecked, luckily without very serious injury to the pilot. The racing engine of this seaplane was the first of a new design for which the name Mercury was revived. It was quite remarkable for those days, developing 990 h.p. for 680 lb. weight. It had the same type of general construction as the Jupiter but with an inch shorter stroke and, later on in production form, was to power several well-known fighter aeroplanes.

We also made experimentally in 1927, a Jupiter engine with exhaust turbo, which ran quite promisingly. About this time we also developed a large, diesel single cylinder unit of 512·6 cu. in. capacity, and did a considerable amount of successful development work on it.

Before continuing with the further development of our family of 9-cylinder, air-cooled radial engines, I must return for a moment to 1924 and give an account of three years intensive work (1924-1926) on the Cherub, a two-cylinder, light aero-engine of 1,095 c.c. 32 h.p., at 3,200 r.p.m. In that year the Air Council offered a £3,000 prize for a light aeroplane competition to be held at Lympne, near Folkestone. This was well supported and the Engine Department produced a batch of 25 Cherub engines. Frank Barnwell designed a machine called the Brownie for the Cherub, over which there was a certain amount of official difficulty during the eliminating trials. Barnwell pluckily took up the machine, looped it and put it through its paces, which enabled the aircraft to enter the competition. Eventually, Shackleton's Beardmore Wee-Bee won, with the Cherub, and Cyril Uwins was second with the Brownie, also with a Cherub. Rather rashly I had built a few of these engines with a geared propeller, which obviously offered a better performance on paper. However, due to torque recoil and no flywheel they were very rough during acceleration

FIGURE 6. Gourdou-Leseurre with helmeted Gnôme-Rhône-built Jupiter engine, 1923.

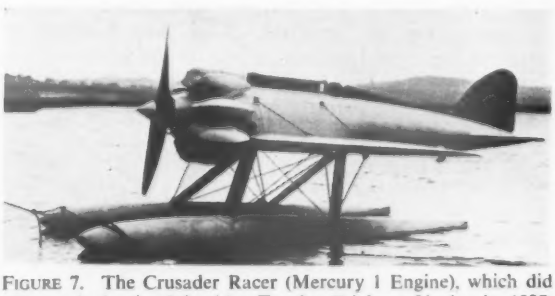


FIGURE 7. The Crusader Racer (Mercury 1 Engine), which did 271 m.p.h. in the Schneider Trophy Trials at Venice in 1927.

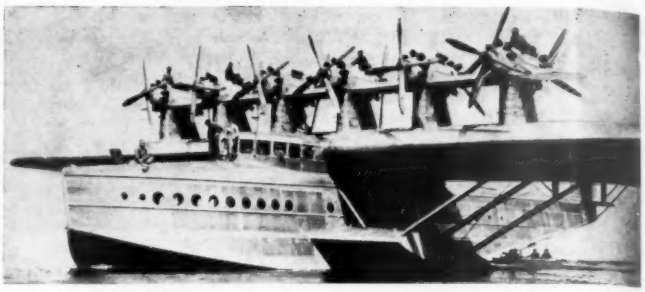


FIGURE 8. Dornier D.O.X., 12 Siemens Jupiters.

and broke their engine mountings. A few enthusiasts, including Butler and Swinchatt, were up all night in a shed on Lympne aerodrome, converting them back to ungeared types, so that they could run in the competition.

In 1925 the Royal Aero Club held a three-day race meeting for this same category of light aircraft and the Cherub was outstandingly successful, winning eight out of ten Prizes. In 1926 the *Daily Mail* followed up with another light aeroplane competition for which the cubic capacity of the Cherub was increased to 1,228 c.c. developing 36 b.h.p. at 3,200 r.p.m. There were several new engines produced for this race and considerable competition. P. W. S. Bulman of Hawkers was easily first with a delightful little machine designed by Sidney Camm, called the Cygnet, the second place being taken by another Cygnet and third place by Cyril Uwins in the Brownie, all with Cherub engines.

The following year the Cherub carried all before it against stiff competition in a light aeroplane trial in Germany, and won the most important light aircraft race at Dayton, Ohio, in America.

On the completion of these trials it was decided that the Government had made a mistake in specifying such a small engine and for two passengers there was not sufficient power, so no production orders followed from this effort, but it did gain for us a remarkable amount of prestige all over the world. It also taught us that it is inadvisable to mix these small engines with powerful aero-engines required for military and civil work, and that these should be undertaken by a separate Division.

In the mid-twenties we started an extended series of engine bench tests and flight tests for longer periods and at higher duty than I believe any other engine makers had attempted before. On the whole, these were very satisfactory and did the engine a great deal of good. One of the most important of these tests was with the Bristol Express Freighter chartered by Imperial Airways, which ran for a long period successfully carrying freight from London to Paris: the fore-runner of the modern freight aircraft. Chittendon, still with the firm, was the Flight Engineer on this machine. The Bristol Jupiter endurance flight by Colonel Minchin of 225 hours and 25,074 miles, finished on 8th March 1926, and was completed successfully without any overhaul or replacement, Griffiths accompanying the machine. This was followed by another high speed endurance test on the same machine later that year, again by Colonel Minchin with Freddie Mayer as passenger, to the main capitals of Europe.

There followed in the late twenties, Alan Cobham's successful flight around Africa in the Short Valetta float machine with three Jupiter engines, a 300 hour test in the Bristol Type 109 machine under official observation at Farnborough, the Duchess of Bedford's record flight to India and Capetown, and a whole string of other pioneering flights with Bristol engines. A good deal of Test Bench development at full throttle was embarked upon, requiring some major design changes, before we could run first 50 hours, and subsequently 100 hours at full throttle, maximum revs without failure.

We were proud of Whitehead's tooling for interchangeability on our current production engines, and it was arranged with the A.I.D. that six standard engines, which had been accepted off the production line, should be brought back into the shop, stripped down, and all the parts intermixed and then reassembled and retested. This test went off with complete satisfaction and for the size of output we were doing at the time, this was a staggering tribute to the standard of manufacture, which I doubt has ever been surpassed on this scale of output.

I feel that our success during those years was due in no small measure to the devotion of the team to an ideal, concentration on one type of engine, aiming at the very highest class of workmanship, and never letting up on a component when it failed, until we had beaten it. In this way we achieved a standard of reliability which I believe was unknown in the aero-engine field up to that time.

Two or three years after Leslie Johnson arrived, we were able to improve our knowledge of fatigue, and thus take the first steps towards a fully equipped fatigue testing laboratory. He also investigated troubles arising from faulty machining which in turn led to a number of improvements in machining techniques. We advanced the standard of material inspection, and for the most important components, raised it to 100 per cent.

In successfully establishing these refinements, it must be realised that there was not available in those early days the excellent equipment for non-destructive testing that is on the market today, such as ultrasonic techniques, penetrating radiation, spectroscopy, etc. A close and regular collaboration was built up with the alloy steel

FIGURE 9. The Russian Tupelov ANT 14, five geared German-built Jupiters, 1929.

makers and stampers for improving quality and uniformity of steel ingots, forgings, and so on. Considerable help was received in this direction from J. H. S. Dickinson of English Steel Corporation, Dr. W. H. Hadfield of Firth-Brown, P. B. Henshaw of Kayser-Ellison, and J. D. Julian of Firth-Derihon.

We pioneered drop forgings in light alloy for crank cases, cylinder heads and several other engine components, although Siddeley were ahead of us by a few months in the forging of pistons. We also initiated the solid master rod and the maneton friction grip type of split crankshaft. These original features played a prominent part in making Bristol engines more rugged and reliable, and many were adopted in American engines.

The initial work on light alloy forgings was done for Bristol by James Booth and English Steel Corporation. Later on we had wholehearted support from Wallace Devereux who put unsparing effort and energy into meeting Bristol's need for light alloy forgings. His firm of High Duty Alloys laid down special plant for this purpose. In fact it became a by-word that wherever Bristol sold their engine licence "Dev" would, before long, install a light alloy plant there also. This was obviously good business, but the wide experience he gained undoubtedly improved the quality of our product.

I remember being indignant at a scathing article in one of our best known non-aviation engineering papers, castigating us for the ridiculous procedure of asking for our cylinder heads to be finned from a solid forging, and in effect saying that designers who produced this type of design should be put away. Actually this article was used by our competitors to some effect, but by the time of the outbreak of the Second World War we had dispensed with poppet valves altogether and the Americans were going over to forgings as quickly as possible, even for their two-valve heads which had a much stronger bridge between the valve seats than was possible with our four-valve penthouse-roof type. Undoubtedly the high m.e.p. that the Americans carried with their exhaust turbo superchargers, as on the B.17 during the War and for their Civil transports after the War, would never have been possible with castings.

On some of our highly loaded Jupiter components we were only initially successful by obtaining certain difficult forgings from one particular firm. The material for these forgings came from Sweden, was made in small ingots from a special pure steel produced in charcoal furnaces. Our valve springs were made from specially cold drawn high tensile wire which was manufactured from Swedish ingots, being centreless ground before winding to remove decarburisation defects.

In the late twenties the A.I.D. tackled us strongly to get rid of these special material techniques which was of course absolutely the right thing to do, and stood us in good stead when the War came. But for the first few years our problem was to get a reliable engine.

In 1929 the S.B.A.C. staged their second Aero Show between the two wars, at Olympia, and I think it may be said that our engine was one of the great successes of the Show. We staged our fully forged engine with heads machined from the solid in series production, with a supercharger maintaining rated power to 9,000 ft., on which Whitehead had made a remarkable job.

By the end of 1931, 7,736 engines had been produced by the parent company and their different foreign licencees. This was a record production for any single make of aero-engine since the First World War.

The foundations of General Weir's hopes for our engine being suitable for civil aviation, as referred to earlier, were well laid in the first ten year period, as many European Airlines chose Bristol engines for their long range routes. The most important were the K.L.M. Fokker VII in 1925, the D.H.66 with three Jupiters in 1927, the Handley Page H.P.42 with four Jupiter X FBM in 1930 and the Short Kent with four Jupiter X FBM in 1931.

The Second Decade

With the rise to power of Hitler in 1933, and his intensive military developments under the Nazi Régime, the British Government embarked upon an air rearmament programme in which Bristol engines took an important part both in the experimental and production spheres.

In consequence of this increased tempo it is difficult, in a lecture, to give a correct picture of all that took place in the right chronological order. Therefore each major subject is dealt with as a whole. I will begin by describing the final history of the four-valve, 9-cylinder, $5\frac{3}{4}$ in. bore family of radial engines, which came to its zenith about 1935.

All our main engine designs had had four valves with the exception of the first 14-cylinder double row Mer-

FIGURE 10. Handley Page Hannibal H.P.42 at Croydon. Four Jupiter X FBM engines (geared and supercharged).

cury, produced at Straker's before we joined Bristol, which had three. This four-valve arrangement gave us better breathing than our competitors but was a problem in making a good job of the valve rocker mechanism and avoiding oil leaks. When I first went over to America in February 1927, I was worried about their two-valve engines and the cleanliness of their enclosed rocker gear, but I decided it was too late to make a change and I anticipated there would be some limitations and complications on breathing as powers went up, as proved to be the case; so we decided to stick to four valves and run the engines faster. This meant that before long we were concerned about propeller tip speeds, and we had to introduce a reduction gear to the propeller shaft. Actually, we employed the French Farman design for which we bought the licence. At first we approached this problem with some apprehension, but the Farman gear proved to be a blessing in a respect we did not anticipate as it entirely damped out the main torsional vibration in our crankshaft system, and brought it down into a speed range where it was not dangerous.

The geared engine gave us a big pull on slower speed and civil aircraft at this stage in our development which, for a time, caused our competitors some concern, but the Americans beat us to it by introducing a variable pitch propeller as a standard production job. This gave them a more efficient power plant than our engine running at higher speeds and a geared down propeller.

Our output of engines at home rose steadily, the later editions of the 1,750 cubic inch engines being known as Pegasus. It was employed on general purpose, bomber and civil types, while another model of the same layout but with one inch shorter stroke was known as the Mercury and this powered many successful fighters both at home and abroad. Both types employed forged heads and mechanically-driven superchargers, and included a number of new developments.

Abroad also the output of Bristol-designed engines rose, mainly in France, Italy, Germany and Japan. Gnôme-Rhône in France actually pioneered the Farman reduction gear ahead of us.

The Alfa Romeo Bristol engine production at Milan was of a very high standard. They were artists at good workmanship. During the second decade they made many hundreds of Bristol engines under licence. Their engine testing was even more stringent than ours and after every 25 production engines they ran a 150 hour type test. They were sceptical about the altitude rating for our engines and made a special transportable test bed which was taken to the top of the Stelvio Pass to a height of 10,000 ft. The tests made there compared very favourably with those we did at Bristol for altitude rating.

During the second decade we undertook three interesting, purely research contracts for the Air Ministry in which the then D.S.R. David (later Sir David) Pye took a considerable interest. All these engines used basic components from our current poppet valve series engine. The first was called the Orion and was a second effort at an exhaust turbo. It was not successful due to excessive turbine casing distortion; the second was the Phoenix compression ignition engine which ran very well and obtained the world altitude record for diesel engines; the third was the Draco with petrol injection which also ran successfully and encouraged our considerable interest in the principle but never had the necessary backing. My summing up of these research efforts is as follows:

No other British engine maker was successful with the exhaust turbo and, generally speaking, it was not well received at home. It was necessary for a major war to bring out fully the advantages of the system and justify the considerable research expenditure necessary. This was achieved by the Americans in the Second World War and used with considerable success on the B.17 Fortress bomber and Thunderbolt fighter.

Our efforts, both in the first and second decade on diesel research, inspired by the hope of cutting out fire risk and gaining greater reliability, were definitely promising but the increase in octane value of aviation petrol, just about this time, killed this idea.

The advantages of petrol injection for altitude work were not appreciated nor did it seem at the time possible to set aside the research funds for an accessory maker to tackle the job properly. Again it was the war which showed the advantages of this principle on German fighter aircraft. Although after the war a satisfactory petrol injection series of Centaurus was developed and is, I understand, functioning satisfactorily in the Beverley, I consider the advantages of

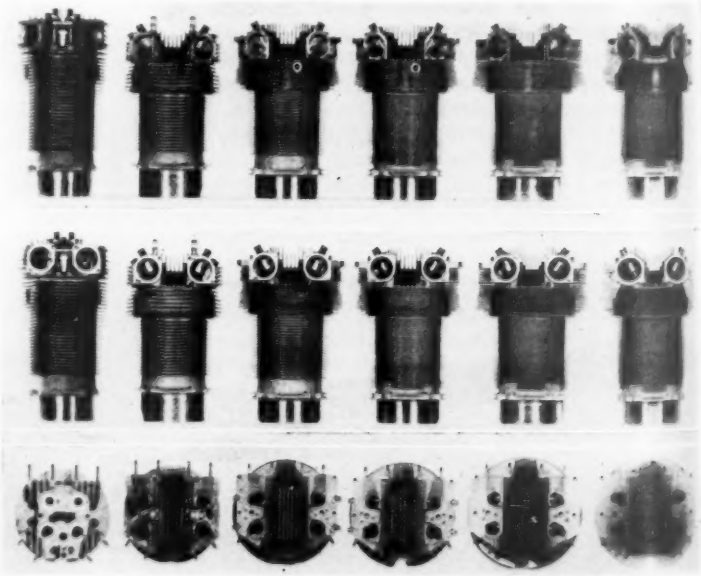


FIGURE 11. Poppet valve cylinder development. The cylinder barrel was machined from the solid and afterwards nitrided, and the head was machined from a light alloy drop forging.

the system have never been appreciated in Great Britain.

To match developments in fuel octane rating in the early thirties we had one last drive on our 9-cylinder poppet valve engines and produced what we called the "lightened series" from which we obtained 960 b.h.p. for 1,015 lb. These engines were employed on a number of successful aircraft right up to the early days of the war. To achieve these powers entailed a number of developments including nitrided crankshafts and cylinders with increased finning, and KE 965 exhaust valves with stellited seats, Brightray heads and hollow nitrided stems with sodium cooling, features which were well ahead of any other British aero-engine maker. The forged cylinder head, which I referred to in the first decade, was refined in design by adding fin area and introducing a new valve seat technique. We also pioneered and developed the separate accessory gear-box, originally because there was not room on the limited radial engine rear cover for the latest requirements of the aircraft constructor but in practice it was found to be a satisfactory and economic solution. All this work entailed lengthy endurance and over-load tests on the bench and in the air, before releasing the engine for production.

To meet the increased demand on this last series of poppet valve engines we planned the final additions and modernisation of the machine shops on the west side, and from then onwards an entirely new production plant was laid out on the east side to deal with our new engines which I shall refer to later.

By the end of the mid-thirties Bristol engines were predominant on all the airlines of the Old World. In 1934 the Chairman of Imperial Airways, in his Annual Speech, said that the British taxpayer got far more value for his money in Civil Aviation than the taxpayer in any other country in the world, and this capacity for intensive trouble-free operation was in no small degree due to Bristol engines. At that time Imperial Airways were using Bristol engines exclusively on all their long-range main routes and maintaining their services efficiently on a pool of less than 150 engines, most of which had thousands of hours service behind them, and the standard period of overhaul was 550 hours.

By 1935, 12,000 Bristol poppet valve engines had been produced and sold by Bristol and the 16 licensees. This was a record production for any country on any one engine design and cylinder bore since the First World War.

The most outstanding contributions made by Bristol poppet valve engines during this second decade, which did much to enhance their world-wide reputation were:

(*a*) The Mount Everest Record: in 1933, a special mission sponsored by Lady Houston, and led by Air Cmdre. Fellowes and Col. Blacker, made successful flights over Mount Everest with two Westland machines using standard Pegasus engines.

(*b*) Altitude Records: The 1929 Jupiter world height record; between 1932 and 1937 four World altitude records:

Cyril Uwins, Sept. 1932, Vickers Vespa, Pegasus engine: 43,976 ft.

R. Donati, April, 1934, Caproni 113, Pegasus engine: 47,370 ft.

F. R. D. Swain, Sept. 1936, Bristol 138A, Pegasus engine: 49,967 ft.

M. J. Adam, June 1937, Bristol 138A, Pegasus engine: 54,000 ft.

H. J. Penrose, May 1934, Westland Wapiti, Phœnix diesel: 27,453 ft.

The first, by Cyril Uwins, paved the way for further developments in the engine and aircraft, the official tests being made by R.A.F. Service pilots.

(*c*) In November 1938, three Vickers Wellesleys broke the world's non-stop endurance

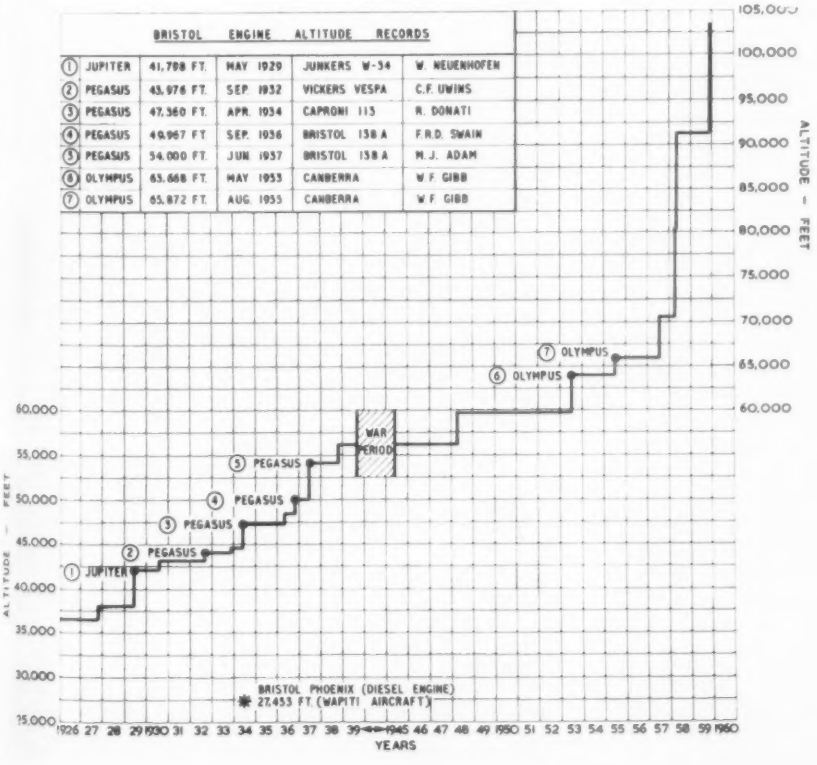

BRISTOL ENGINE ALTITUDE RECORDS
① JUPITER 41,788 FT. MAY 1929 JUNKERS W-34 W. NEUENHOFEN
② PEGASUS 43,976 FT. SEP. 1932 VICKERS VESPA C.F. UWINS
③ PEGASUS 47,360 FT. APR. 1934 CAPRONI 113 R. DONATI
④ PEGASUS 49,967 FT. SEP. 1936 BRISTOL 138 A F.R.D. SWAIN
⑤ PEGASUS 54,000 FT. JUN. 1937 BRISTOL 138 A M.J. ADAM
⑥ OLYMPUS 65,668 FT. MAY 1953 CANBERRA W.F. GIBB
⑦ OLYMPUS 65,872 FT. AUG. 1953 CANBERRA W.F. GIBB
ALTITUDE - FEET
105,000
100,000
95,000
90,000
85,000
80,000
75,000
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
WAR PERIOD
BRISTOL PHOENIX (DIESEL ENGINE)
* 27,453 FT. (WAPITI AIRCRAFT)
1926 27 28 29 1930 31 32 33 34 35 36 37 38 39 1945 46 47 48 49 1950 51 52 53 54 55 56 57 58 59 1960
YEARS

FIGURE 13. Aircraft world altitude records, with, inset, Bristol records.

record using Pegasus engines. The distance was 7,162 miles and this record was not beaten until some years after the Second World War.

(*d*) By 1938 the full fleet of 38 Short Empire flying boats with Pegasus engines, ordered by Imperial Airways, were in full operation and doing magnificent work. The engine installation incorporated several original features.

(*e*) In the Summer of 1939 the first proving flights, non-stop from England to America, were being undertaken regularly and with complete success with Short flying boats.

(*f*) Signal success was achieved by the Hawker Audax and Hind aircraft, both as regards performance and reliability, when fitted with Bristol engines and Townend ring cowling, in Middle East countries where the climatic conditions favoured air-cooled engines.

In the Autumn of 1935 Sir Hugh Dowding had the first talk with me about the possibilities of embarking on the Shadow Engine Industry, by which the latest Bristol poppet valve engine would be manufactured by six of the most important motor car manufacturers in the Coventry and Birmingham areas. At that time it was a purely precautionary measure entailing full jigging, but only a token production order of about 50 engines. I encouraged this idea as much as possible because I knew that, apart from the soundness of the engine, we had had a unique experience on our licence manufacture which would give us the necessary background to put this over more quickly than anyone else. In fact when the Bristol engine licence business began to mount up rapidly in the mid twenties I had appointed a Belgian engineer Lavrillé, who had joined me way back in 1917, to head an office for the translation and metric conversion of our engines and over 20 years he had built up an experienced and expert staff of about twenty for this work.

Eventually, with the rising tempo of Nazi aggression, we were given an absolutely free hand by the Government with regard to this Shadow Engine Licence business and the motor car firms entered into the manufacture wholeheartedly and produced a very fine job. To start with a few of our processes were challenged and in a few cases different machine tools were preferred. But in every such case the Bristol methods were found to be best. Later on when the same firms went over to the sleeve valve engines, this stood us in good stead, as we had their full acceptance on a much more specialised plant and equipment.

To meet the large demand for new machine tools both for the parent organisation and the Shadow factories, Fred Whitehead opened an office in North America which actually designed and ordered a great deal of special purpose plant. This proved to be an excellent move and greatly assisted the Shadow Industry to get going quickly. The Shadow Industry group was managed by a committee consisting of representatives from the Government, Bristol and the motor car firms. Arthur Elliot and a small team from Bristol acted in a resident liaison capacity. The whole scheme worked harmoniously and in a remarkably short time Bristol engines were being produced, which soon proved to be as good as the parent firm's products.

Before describing our efforts to produce new types of aero-engines, I will touch on the early developments of the East Side Engine Works. The Bristol Board were always forthcoming in giving us a good proportion of Bristol engine royalties for the purchase of new plant, and in 1933 the first stage was completed of an entirely new Bristol Engine Plant in which a great deal of special purpose machinery was put into operation for the first time. We also laid down a number of new silenced test beds on the east side for engine testing, designed by the Company. Norman Rowbotham had by this time returned from France and become General Works Manager and he and Fred Whitehead put a great deal of energy and drive into this new factory which became one of the finest production plants in the country.

Over this period, and as a result of my many visits to America, we pioneered a number of new techniques, which in most cases had been originated in this country, but were made practical production equipment in U.S.A. by American business initiative, such as surface finish testing equipment and oscillograph, gas analysing and strain gauging equipment for engine testing.

About this time we started an Instrument and Electrical Department under Harvey Mansell, which developed and later designed and made special equipment that few engineering shops in the country possessed and which was a great help in tracking down difficulties.

During one of my trips to the Bliss Engine Company, which was making our engines under licence in America, I took an option on the Hamilton V.P. propeller, which our Board did not approve of. This was in the early Autumn of 1933. I was worried about this propeller efficiency position and went to see Sir Hugh Dowding. He was sympathetic, and suggested I should take an order for two variable pitch propellers from him, to be made to the Hele-Shaw design which he believed was most promising, and which was being developed rather slowly by the Gloster Company. Arising from this talk, Bristol's took the order for these two propellers and with the utmost collaboration from Hugh Burroughes and Harry Folland, we set to and made a new design: we arranged for Milner, the original Hele-Shaw designer, to be transferred to us. We were fortunate in quickly hitting on the main cause of their trouble, namely oil pressure drop due to hub distortion, and by making the hub forging solid like the banjo of the back axle of a lorry, we cured the trouble and did a most successful ground type test, the first ever run on a British V.P. propeller, followed by a 100 hour flight test in a Gloster Gauntlet with a Mercury engine.

Our Board, however, were still loath to go into the propeller business but after a talk with Messrs. Sidgreaves and Hives of Rolls-Royce in London, knowing that they were also working on a similar Hele-Shaw propeller for Sir Hugh Dowding, I told them of our success and suggested that we form a joint company to manufacture these propellers. This was agreed, and the Bristol Directors fell for the idea, and the result was Rotol—the first two letters standing for Rolls and the last three for Bristol, invented by Bill Stammers who became the first General Manager of the Company. To get going quickly we started in a rented factory at

Gloucester, but in the Autumn of 1936 the present site was found and a new factory built.

I must add two more episodes to confirm my view about the importance of correct timing and the significance of certain decisions in the fortunes of aircraft undertakings. de Havilland had taken the Hamilton licence and were in production with the two-pitch type, and Rotol had acquired a licence for the Curtiss-Wright electrical V.P. propeller. Bristol incidentally was the first British engine to be cleared for D.H. propellers. In the Summer of 1939 Sir Wilfred Freeman and Sir Donald Banks called for an urgent joint meeting of Rotol and de Havilland to plan a considerable programme for constant speed propellers to meet the flooding tide of Hurricane, Spitfire and other military aircraft, which had great need for this equipment. I remember sitting at this meeting in Berkeley Square on a hot Saturday afternoon sighing for the Solent, but tremendously important decisions were taken that day which enabled us to have constant speed propellers just in time for the Battle of Britain, when each one that came off the line was counted as a precious article, and despatched by special messenger to one of our fighter squadrons in the London area.

On Christmas Eve 1958, when I was in New Zealand, I had word that the Rotol Company had been acquired by the Dowty Group. I have just concluded seven years consultancy for this Group and it was a great pleasure for me to hear that a company I had played some part in initiating and a firm for whom I was carrying out negotiations in the Antipodes, were now being welded together.

There is another story which has nothing to do with engines but aircraft. In 1934 I gave a lecture at the Spa Hotel to the British Yacht Club on my experience during a recent tour of America and the flights I had had in one or two new American machines, illustrating them by slides. After the lecture, Blos Lewis, editor of the *Bristol Evening World*, a Rothermere paper, asked why it was not possible for Britain to have as clean and fast machines. I said it was perfectly feasible provided the authorities who placed the orders had the initiative, and knew what they wanted. He asked if my firm could make such a machine and I said that it was not my job, but I was sure they could. At his request I went to London with him the next day and talked with Lord Rothermere for two or three hours: I brought back to Bristol the promise of an order for a machine which would at least be equal to anything that the Americans had done. Frank Barnwell collaborated to the full and produced the classic "Britain First," with two Mercury engines which went to Martlesham and shook everybody by its performance and good handling qualities, and within a few weeks the Bristol Company had their first order for 150 mid-wing Blenheims. This again shows how little things can start big ones in Aviation.

In 1936 the Farnborough 25 ft. full-scale wind tunnel was opened for cowling and cooling research. The first test consisted of a complete Bristol engine with ring cowling and V.P. propeller, the second test being with a complete Gloster Gauntlet and Mercury engine. As a result of these tests, substantial improvements in drag, cooling and cowling control, and the maintenance of even cylinder temperatures, combined with appreciable fuel saving, were made.

In the early thirties I was becoming concerned at the way our programme was locked up to a 9-cylinder engine; we had thrown out an 18-cylinder engine project way back in 1920, but had never had time to get around to tackling a new design again. Now with the continual urge for more power, it looked as if we might be seriously up against it. I felt strongly that the valve gear on a double row engine with four valves was almost an impossibility to contemplate. Actually, during the Second World War, I learned from the Italians when I led a Mission there in 1944, that Alfa's had made a double row radial with Bristol four valve heads, and from photographs in a book I have seen lately, Bristol's licensee in Japan did so also, but it looked a clumsy job.

Feeling we should not attempt such a design, I set a special office aside at Rodney Hall under Frank Owner to produce a double row, double octagon 16-cylinder engine with twin overhead camshafts and inclined valves, which we called the Hydra. This was a neat, small diameter engine with direct attack cams which worked well, and on which we achieved oil tight rocker gear, and a really neat rear exhaust system. We made one profound mistake, however. With a short stroke engine, we thought we could do without a centre bearing by using a very large diameter stiff shaft, but we were wrong. In the early stages, this engine was flight tested, and the vibration from it at certain speeds was such that it was obvious that the project had to be abandoned, in spite of an attractive layout which initially seemed to hold out hope of meeting our future needs.

Fortunately, by this time the single sleeve, breathing system which basically had great possibilities, and had first intrigued me way back in 1914, was coming along well at Bristol with Major Bulman's encouragement, and the help of early work by Harry Ricardo. The Birt-McCollum patents having run out, we had set to, about the Autumn of 1927, developing a sleeve valve engine. We started with an inverted 'V' two cylinder engine of Mercury dimensions, and then went on to a 6-cylinder in-line. Eventually we concentrated on several single cylinder units of Mercury dimensions, on which we tried out a wide range of porting, fin cooling and different materials. We went through many vicissitudes, and never did I come nearer to accepting the word "can't," although from the first, the system showed promise of meeting all our future needs.

Nothing ever worried me like the sleeve valve development, and a number of my colleagues felt that we had backed the wrong horse. Finally after many thousands of hours on single sleeve valve engines, most keenly and intelligently supervised by Harvey Mansell, we got a complete engine running, and could make it pull excellent power with good fuel consumption, but the only way we could stabilise the oil consumption was to squeeze every sleeve round after hardening, and then grind each piston and cylinder to fit the particular sleeve.

Major Woods-Humphery, General Manager of Imperial Airways, who was always a strong supporter of Bristol engines, gave us great encouragement on sleeves; he tested about a dozen of these handmade engines,

called the Perseus, and we had remarkably good results from them. But we still had to get over the problem of making the engines interchangeable and a practical production job. By this time things began to be critical, and I must give the Bristol Board credit for their complete confidence in me at this time, because we were heavily committed to double row engines, and there seemed to be no practical production answer.

The Nazi menace was already rearing its head and trips to Germany with my friend Devereux convinced us war was coming, and drove me harder than ever to look round for the right solution. There were a number of firms looking to Bristol for more powerful engines, and we had to find the answer. Chiefly through the watchful eyes of Harvey Mansell and Jim Gadd, and their two Research teams, backed up excellently by a strong development and experimental department led by Bill Evans and Harry Higgins, we won out just in time. This would not have been possible without the good work of Firth-Brown, which firm successfully produced our high expansion, nickel-manganese-chrome alloy, centrifugally cast sleeves, and also by the great energy of Freddie Whitehead and one or two machine tool makers whom he encouraged to produce special sleeve valve plant for us, so that we eventually had the production and interchangeability problems for the sleeve valve engine licked.

The evolution of the centrifugally cast high expansion sleeves was a long and arduous development lasting several years and was enthusiastically undertaken by A. E. Thornton of Firth-Vickers. In all some fifty to sixty varying compositions associated with approximately 1,100 heat treatment procedures were investigated and tested both metallographically and physically before the final production sleeve was produced.

In trying to tell the full story of the sleeve valve development, which was undoubtedly by far the longest and most serious battle that we had, for I believe Bristol and the Air Ministry spent over £2 million between them solely on developing and getting the sleeve right for production, I have passed over a number of other important events which took place during the thirties.

In 1936 our first sleeve valve engine of 25 litres, the Perseus, went into series production with the new machine tool plant and tooling.

By the Autumn of 1936 the new Bristol Engine Machine Shops on the East side were in full production, and were operating consistently on a double shift. This was continued without a break for the next 10 years.

During the next two years over 3,000 flight testing hours were put in on sleeve valves on three different aircraft. A special low-wing Northrop monoplane was obtained from America for initial flight testing work on the Hercules, and created a marked impression for good workmanship, and clean design for air-cooled engine installation. Parallel with this flight testing a heavy programme of overload bench testing was undertaken both on the single and main engine involving several thousand hours of running.

In 1937 the first Hercules type of double row sleeve valve went into production and this was another weight off our shoulders as by this time there seemed little possibility of avoiding war with Germany. All this time we were working at great pressure and the leading Engine Department staff were carrying a considerable responsibility, because we appreciated what it meant, were war to break out, with three entirely new sleeve engines to be stepped up rapidly into very large quantity production.

By early May 1938, through a series of meetings running on late into the night, I cleared the drawings for the Centaurus. The first engine was running by the middle of July 1939 and the first type test completed in April 1940.

By the Summer of 1939 the whole Bristol Engine organisation including the Design, Development, Ground and Flight Testing Sections on the West side, and the Production Factory on the East side were full out on our new family of sleeve valve engines, and still hoping for a few months grace to put the finishing touches.

During the three years before the outbreak of the Second World War, a number of interesting aircraft were produced on the Continent with Bristol engines, giving a high performance, particularly French, Polish and Italian Types.

The most important British Military Types with Bristol engines that were ready and in Service Squadrons at the outbreak of the Second World War were:– Blenheim, Bombay, Hampden, Wellington, Wellesley, Lysander, Swordfish, Walrus, Gladiator and Sunderland.

By the outbreak of the Second World War and over the second decade of the Bristol Engine Department, the total number of Bristol engines manufactured by the Parent firm and its licensees amounted to 18,750. This output, although by far the largest from any design in Europe was surpassed in America, where the advance in civil aviation in the years before the war was spectacular.

The War Period, 1939-1945

Looking through old records before writing this paper I found a memorandum of mine addressed to the Board, dated 4th September, 1939, entitled "Bristol Engine Technical Policy in War." I had forgotten its existence. In retrospect we did not carry out all the recommendations contained in it, but a fairly accurate forecast was made of the work that was undertaken.

With the coming of war, our design and experimental team was set a formidable task in rationalising production for wartime requirements where the life of an engine was naturally of short duration. This entailed a great deal of single cylinder, main engine, and rig testing; the substitution of a few alternative materials which were in short supply, and the proving out of American steel stampings. At first it went against the grain to let up on a number of things, but as experience and urgency of output pressed on us, we managed by intensive investigation and testing to make a large number of concessions on new engines and particularly on repairs.

Naturally various troubles cropped up with our much greater production and the less careful service maintenance which required the intensive consideration of our installation and development teams. Our sleeve valve

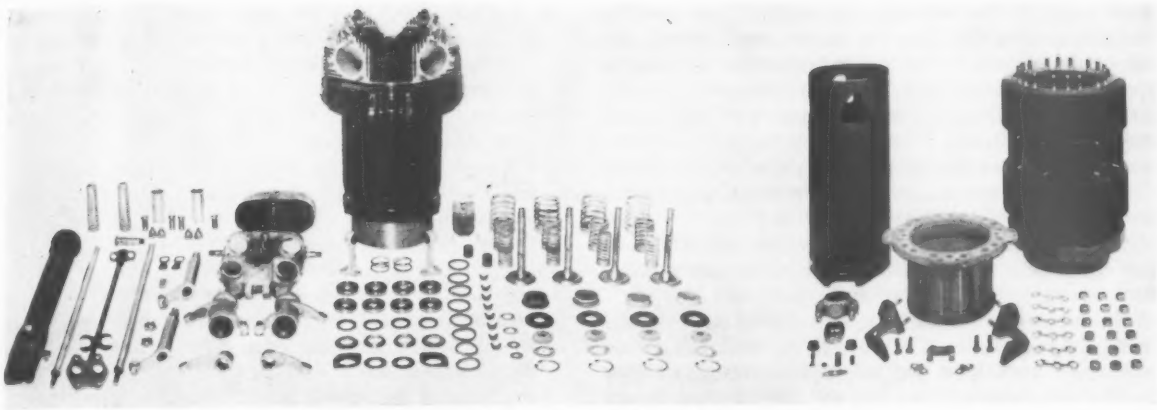


FIGURE 14. Poppet valve and sleeve valve cylinder components.

engines developed certain difficulties particularly on bearings both for crankshafts and superchargers, some of which were our fault and others for which the ball bearing manufacturers were responsible. We had to tackle these problems urgently, and do a considerable amount of bearing redesign.

We had some anxious moments on our double row engine main crankshaft bearings as these were of Swedish origin and although we had been assured that arrangements for their production in England would be complete before war broke out, this proved not to be the case. Further, as the engine ratings were increased we had to redesign these roller bearings ourselves, and undertake the development work. We heard from time to time exciting stories of how our bearings were smuggled to us from Sweden by sea, and gathered that at one time during the war, deliveries of these bearings were about equally divided between ourselves and the Germans. Also that some key personnel from the Swedish firm wanted for the manufacture in England were brought here in the bomb bays of several Mosquito aircraft.

A two-speed supercharger drive for the Hercules had been successfully developed shortly before the war, and introduced into series production. Under wartime conditions, however, this assembly suffered from serious sludging troubles, which caused the burning out of the clutches. Built-in centrifugers were introduced, which were entirely successful, as much as 3 lb. of sludge being frequently collected. The Centaurus was also fitted with similar centrifuger units towards the end of the war.

I believe the rationalisation and concession work on new and repaired engines was satisfactorily tackled by the Design side, and that this whole matter was in good shape by the beginning of 1941. I could not, however, say the same about some of the major redesign work. The two-stage mechanical blower for the Hercules to be employed on the special high altitude Wellington, never matured in time. Certain unsatisfactory features of the design took so long to cure that the value of the engine disappeared because the particular duties intended for the special Wellington were abandoned, and this type was never proceeded with in series production.

The development of the American G.E.C. exhaust turbo for the Hercules was also never brought to successful fruition. The engine maintained excellent power at altitude on the bench, and the sleeves were quite happy with the resulting back pressure, and no overheating was experienced, but difficulties were found with surging.

Had the official outlook been favourable to a fully dispersed design for the blowers, schemed on the lines of the American B.17, success might have been achieved, but this proposal was not approved and at the time it seemed difficult to find any British aircraft firm that would face the considerable machine redesign work entailed.

These failures, for which I took full responsibility, were naturally a great disappointment to me. Some most promising new design work was undertaken by the Design and Development Departments on an improved copper cylinder head and a double entry blower, both of which would have paid good dividends, and I believe could have easily been brought into Production during the war. Resulting, however, from a close liaison with the Ministry of Aircraft Production officials and the Production side of the Company, born of contacts made in connection with the Shadow Industry, over which at that period I had very little influence, these obvious improvements which, in my view, should have gone into the sleeve valve family of engines post-haste, were rebuffed. We were therefore not able to show the rapid development on the Hercules that was provided by the Rolls-Royce Merlin under a wholehearted single control.

With the increase in engine rating, it became urgent to restrain the cylinder barrel expansion of our sleeve valve engines. This entailed considerable experimental work for our Material Contractors, together with single and main engine testing. Eventually a solution was found by using an aluminium-silicon forging of lower expansion ratio combined with increased finning. When these features were cleared experimentally, the Production side was faced with the problems of new tooling for the finer pitch fins on a material which was a good deal harder to machine. Finally, all these difficulties were overcome which resulted in a distinctly improved engine in production.

At the outbreak of war, Bristol products engined 52 per cent of the R.A.F. but since about 1938 we had suffered some setbacks in being selected for new prototype aircraft, in spite of the excellent results of the full-

scale tests at Farnborough on cooling and cowling research. I think this lapse was due to some extent to the outstanding success of the in-line liquid cooled engine in special racing installations, such as the Schneider Trophy aircraft in which surface radiators and oil coolers were employed. Be that as it may, I felt strongly that in the early stages of the war the promise given by an excellent Centaurus type test in April, 1940, was not appreciated in time. I managed to send a Centaurus engine to Sydney Camm for his new fighter late in 1940, but official action had the engine taken out of the machine, and in consequence we lost at least two and a half years.

In fact it was not until the outstanding performance of the German Focke-Wulf 190, the American Thunderbolt, the Curtiss P.34 and the Japanese Zero, all with similar air-cooled radials, that any serious interest was revived. The results of the Hercules in the Halifax 3 and Lancaster 2 experimentally were convincing, resulting in the Halifax going into production with Hercules engines. The Centaurus went into production in the Blackburn Firebrand, Bristol Buckingham and Brigand, Vickers Warwick, Hawker Tempest II, and in the Hawker Sea Fury, which became one of the fastest fighters of the war.

Actually this misunderstanding as regards drag had official recognition in 1942 but at the time was not recognised as such, when the standardised circular power plant was adopted for British radial and in-line engines with practically identical results. This followed on a similar earlier scheme, which had been put into operation in Germany, initiated by the Junkers Company.

While not wishing to make any excuses for my apparent lack of imagination and leadership, I think few of the Powers That Be of that period were aware of the enormous strain the senior members of the Bristol Engine Department had been under for five years before the outbreak of war, when we burned our boats, and went over irrevocably to the sleeve valve principle for all our new double row engines of greater power.

During all this period we had hanging over us the need to make good on the sleeve valve, and we were in fact literally working on a war basis all this time. Other engine firms were certainly working just as hard, but mostly on traditional types of engines, upon which they had been concentrating for many years. I have little doubt that Leonard Butler, Harvey Mansell and Harry Higgins, among others, made the supreme sacrifice in their own quiet way for our Engine Department work, just as much as any fighting man on active service.

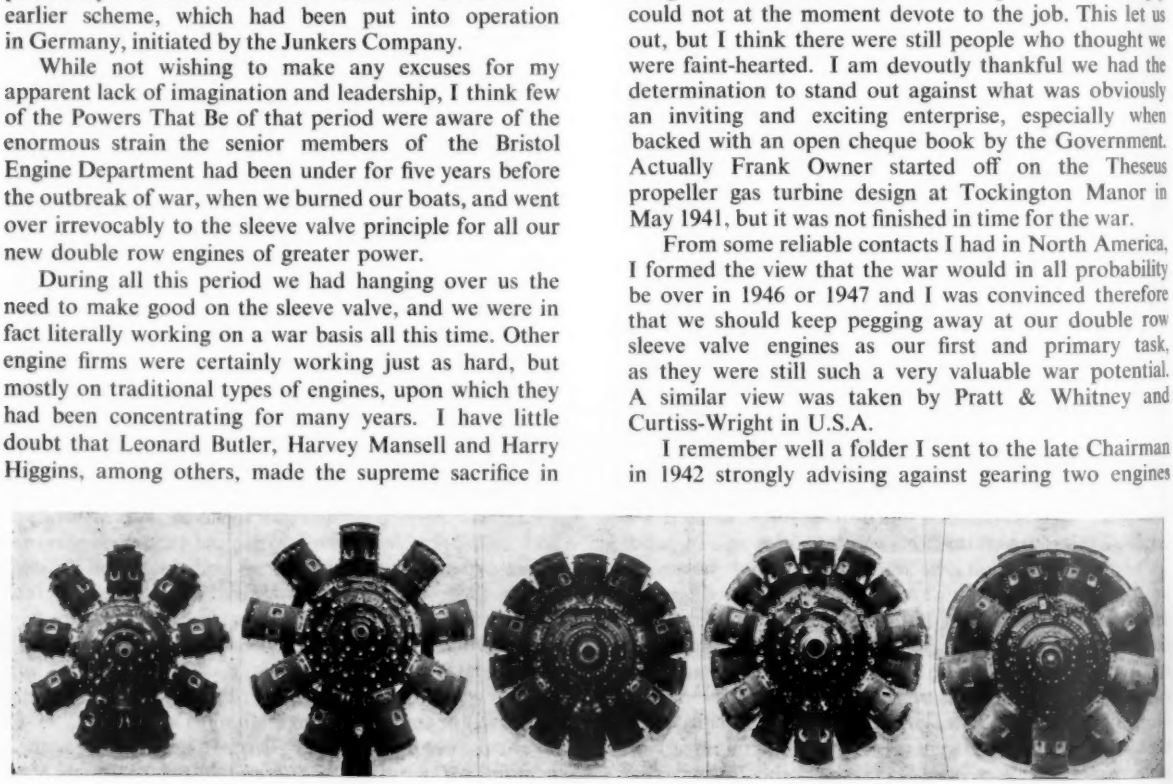
I have naturally come in for a good deal of criticism for being slow on taking up the gas turbine on behalf of Bristol. Immediately after the war this worried me a great deal, but in mature retrospect I am convinced that if I were faced with the decision to make again, I would make no change. If we had attempted to go over to the jet engine with this new sleeve valve family of engines still on our hands, I think it would have been disastrous.

Frank Whittle talked to our technical team early on, and because we felt we must not be interested—although for the previous twenty years we had always shown willing to try anything once as readily as any other British engine maker—higher and more influential interests tackled the Bristol Board again about our lack of interest in jet engines, which resulted in further investigation.

Frank Owner produced a report which said that at the time of the first approach to us, the combination of a centrifugal type of supercharger of the best efficiency we knew of, matched to a turbine with a limiting temperature which we believed would run without failure, would not in fact, "pull the skin off a rice pudding." A considerable amount of entirely unexplored investigation was required on these two main components in order to tip the scales the right way, so that a practical and useful prime mover could be produced. This design and research effort in manpower, we simply could not at the moment devote to the job. This let us out, but I think there were still people who thought we were faint-hearted. I am devoutly thankful we had the determination to stand out against what was obviously an inviting and exciting enterprise, especially when backed with an open cheque book by the Government. Actually Frank Owner started off on the Theseus propeller gas turbine design at Tockington Manor in May 1941, but it was not finished in time for the war.

From some reliable contacts I had in North America, I formed the view that the war would in all probability be over in 1946 or 1947 and I was convinced therefore that we should keep pegging away at our double row sleeve valve engines as our first and primary task, as they were still such a very valuable war potential. A similar view was taken by Pratt & Whitney and Curtiss-Wright in U.S.A.

I remember well a folder I sent to the late Chairman in 1942 strongly advising against gearing two engines



Acquila Perseus Taurus Hercules Centaurus

FIGURE 15. The range of sleeve valve engines produced during the second decade.

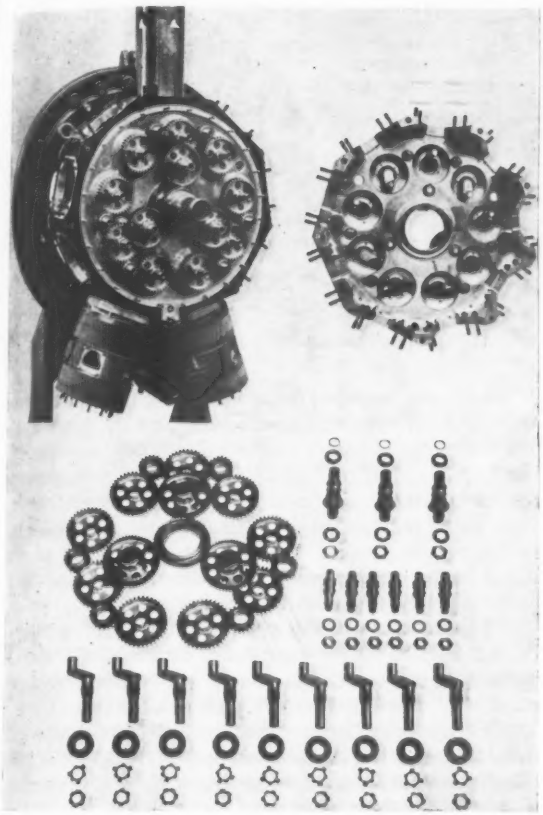


FIGURE 16. Breakdown of timing gear, 9 cylinder sleeve valve drive for the Perseus and Centaurus.

together or an 8 engine installation of any sort, and pressing for the 6¼ in. bore, 4,140 cubic inch, 18-cylinder engine to be proceeded with, having new copper heads and cylinder porting turned round to provide a new exhaust, which I believed would have made a fine engine of about 3,500/4,000 h.p. Both Arthur Gouge and Rex Pierson gave me full support on this, and were anxious to prepare designs for this engine.

My belief was so great in the higher powered double row sleeve valve family of engines for all future multi-engine military and civil types that I considered we had an unbeatable range for at least the next 8 years, and that we should be very strongly placed for civil work in straightforward four or even six engine nacelles, thus giving the Department more time to develop the gas turbine carefully. No other British engine firm was in this fortunate position or had such a promising range of engines for so many years ahead. I wanted to see the first post-war civil air liner emanate from Bristol at about 120,000 lb. as soon as possible after the war, but unfortunately that was not to be. Having been, it was considered, slow on the uptake in going into gas turbines for reasons I have endeavoured to explain, the Company then took the bold step of virtually throwing all their piston engines away at the end of the war, by not undertaking any new design or development on them.

On the 25th September, 1940, we had a serious daylight raid on Bristol. I had gone to London to a meeting at the Ministry of Aircraft Production. That same evening I got back to the Engine Department. Although a great many bombs had just missed important buildings it was bad enough, and gave me some idea of what could so easily have happened. It had affected the morale of the people, and if the Germans had only made a couple of determined attacks within the next week and done the same amount of damage, the story of the Bristol Engine war effort would have been a very different one.

Soon after the outbreak of war the Bristol Engine Department undertook responsibility for a Shadow Engine Factory at Accrington, Lancashire. This was organised by Norman Rowbotham and managed by J. E. Attwood and a nucleus of staff from the parent factory. This plant had a most successful history on Hercules engines.

The sound planning of the Bristol poppet valve engines undertaken by the group of Midland motor car factories bore good fruit, with the result that when more powerful engines were needed from them, they tackled the Hercules with great vigour and got into production in an unexpectedly short time.

Production of the Centaurus was retarded by starting series manufacture at the new underground factory at Corsham near Chippenham. This was a splendid effort carried out with great keenness and efficiency by a special team set aside to make this move. I recall the problem we had to persuade a nucleus of our best men to go over there, but they made a first-class job of manufacturing this engine under extremely novel, but what turned out to be very healthy, conditions. Undoubtedly somebody had to pull the chestnuts out of the fire on this underground bomb-proof factory, and had the war gone on for another year or so, and the German bombing come back to this country, it would have been invaluable.

The most important British Service aircraft employing Bristol engines in the Second World War were the Hampden, Gladiator, Blenheim, Beaufort, Wellington, Beaufighter, Stirling, Sunderland, Swordfish, Lysander, Halifax and Tempest II.

During the Second World War the Bristol parent factories in collaboration with the Midland motor car Shadow fac-

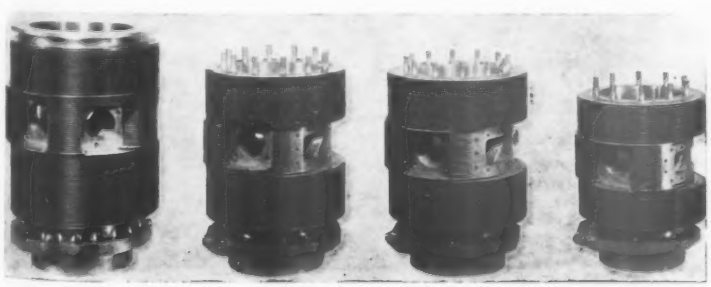


FIGURE 17. Light alloy sleeve valve cylinders for, *left to right*, the Orion, Centaurus, Hercules and Taurus.

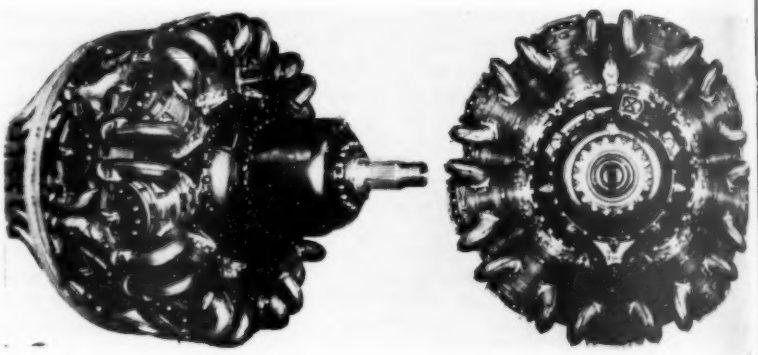


FIGURE 18. Centaurus Engine for the Tempest with rear swept exhaust system for close cowling.

tories, produced the equivalent of 116,200 engines. Taking into consideration a total output of 26,300 engines between the two wars, this brings the grand total of Bristol engines over the period 1920-1945 to 142,500.

The Bristol Engine Department was founded in August, 1920, with 31 people. At the height of the war production there were about 20,000 people employed by the parent company, and with the Shadow factories, 71,850 people employed on Bristol engine manufacture.

Conclusions

What conclusions may be drawn from the first 25 years of the Bristol Engine Department, that might be useful and worth considering in the light of today's problems?

Since I am not familiar with what goes on in Bristol Siddeley Engines today, I may be speaking entirely out of turn in making any suggestions at all, but human nature does not change much, and an independent observer will often see certain features of the game that players miss.

One idea that I had in 1920 has since proved inadvisable and generally unsatisfactory. In those days, I thought it would be ideal to have a combined airframe and engine manufacturing organisation; but it was not long before I discovered that such an arrangement would not work and that other aircraft manufacturers were inclined to be a bit wary about an engine company with aircraft affiliations. It appears quite obvious now, even if it did not at the time, that it is difficult to sell to another airframe builder, when part of your own firm is often in competition with him. This does not mean that an aero-engine company can be successful without a comprehensive Flight Testing Department which is just as necessary as efficient Ground Testing Equipment.

The Board members of such an exacting undertaking as an aero-engine manufacturing company should be predominantly engineering in background and experience, with the inclusion of a Financial Director. Personally I favour the old-fashioned North country method of control by a single Managing Director with a Chief Engineer in charge of the whole technical set-up, including design, research, development, quality control and testing, the design and quality control being vested in an experienced Chief Draughtsman. I believe this is better for engine work than assigning these duties to a Chief Designer, which is standard practice today in aircraft companies, where it is considered preferable.

Quick and confident decisions are highly important in successful aero-engine manufacture, and therefore I do not believe in partners or committees on basic policy, but I am a strong believer in the Chief Engineer having regular meetings with a small number of executives to explain the policy already settled. I always found that explaining the various aspects of engine policy to my staff, including design, quality control, testing and particularly the Materials Laboratory, was of great value.

I believe that as far as possible in all engine matters, there should be a long-term policy concentrating upon a definite school of thought of design, which should be steadfastly developed to its logical conclusion.

The Managing Director of an aero-engine organisation should be technical in the broad sense. He is in effect the Chief Salesman, since only he, assisted by his technical staff, will be in the position to pledge his firm and alter or modify policy on the spot, when selling an engine to an aircraft constructor.

When the design and production interests are split in any high precision engineering organisation such as an aero-engine business, and this occurred while I was at Bristol, both in the Aircraft and Engine Divisions, the product inevitably suffers.

I am accordingly a great believer in that quotation given to me twenty-five years ago by "Dutch" Kindelberger, still the remarkable and outstanding autocratic head of North American Aviation. I had this carved on a wooden plaque and put up in the vestibule of what is now Sir Alec Coryton's West Office Block, and am glad to see it is still there. It reads:

"It may not always be the best policy to adopt the course that is best technically, but those responsible

FIGURE 19. Tempest Mk. II with Bristol Centaurus V.

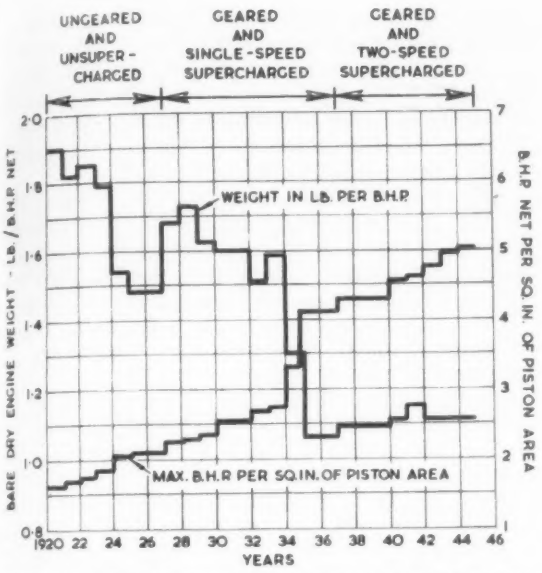


FIGURE 20. Development of Bristol air-cooled radial engines.

for policy can never form a right judgement without knowledge of what is right technically."

I am in favour of notices and reminders throughout the Drawing Offices and Shops on such matters as the effect of sharp corners, scratches, abrasions, and polishing; and the importance of maintaining certain established features of design which have been built up over the years. In fact anything that logically helps to encourage meticulous design and workmanship is worth fostering. A great deal can be done on modern engine techniques in this way to build up morale, enthusiasm and interest. A good components museum in the Design Department, which should include failures, is worth while, and can be of value to young designers and help the budding staff to appreciate different events in the earlier days of a firm, and thereby assist them on their own problems.

No workmanship can be too good for an aero-engine. The highest class of workmanship must not however be confused with finicky, pedantic design which is an abomination to be suppressed at birth.

I believe in basic principles of aero-engine manufacture. The workman of today is better trained and has a better basic education than his counterpart of 40 years ago, but temperamentally he is much the same and can be inspired in the same way. He likes to be told why a certain thing is being done, and as much as possible about the firm's policy. Notices or illustrations that bring home current problems and topics are important and always pay.

I believe that having once made a decision, it must be instilled into the whole team, including those on the shop floor, to put the maximum pressure and enthusiasm behind it; naturally, one can be wrong and when this happens there must be no delay in calling a halt and at the same time telling all concerned, including the workpeople, why it has been necessary to shut down on a job.

Once a decision has been made to take some action or incorporate a change, the correct following-up steps must be put into execution promptly. In my experience in aero-engine work, unless this is done, it is so easy for decisions to be taken and just nothing further happen.

I deplore the unbalanced statements that are often made nowadays by the Industry when a new development is just starting and cannot, at that stage, be assessed as to its possible success or otherwise. Frank Barnwell was a great stickler for the facts, and we all admired him for it. Whereas I believe the official security regulations are often frustrating and sometimes do not make sense, it is misleading and dangerous to quote engineering estimates as facts before they are proven.

In the early days of the piston engine when design work was more of an art than a science, it was not possible to ensure that a new engine would be a success. By this I mean it might be a failure technically or it might have been badly timed and too late to meet the need that was already satisfied by another engine. Today I would suggest that no gas turbine engine built by a reputable firm, with adequate background, need be a failure technically, but it can be badly timed (the wrong size at the wrong time) relative to a competitor. In the final analysis, the only success that can be recognised in the aero-engine field today is that the engine goes into series production.

In my travels around the world since the war and my visits to organisations with huge design and development staffs, fortified by all the modern techniques such as computer and operational research departments, I have been intensely interested to note that at the hard core of these design teams, the successful ones generally possess a practical small nucleus of people who, as soon as a new project is decided upon, quickly try out and evaluate the likelihood of success or otherwise of it. This is exactly what I attemped to do at Bristol but in a very simple way. I particularly noted the people who constituted this hard core, perhaps under a dozen, and the extent to which the guiding genius of the whole project relied upon representatives from the Quality Control, Testing and Laboratory Departments.

While I appreciate that with the present working conditions strict discipline of the order I was accustomed to, is extremely difficult and almost impossible to enforce, nevertheless if it is tempered with sincerity, and the knowledge that the person who is giving the order knows what he is talking about, it is remarkable how the British workman will respond even today and, what is more, he really likes it. It is worth noting how much this approach can affect efficiency, rapid solution of a problem, and keeping to a promised date.

When I go into a big engineering works today, no matter whether it is an aero-engine factory or an automobile or other precision undertaking, I am struck at how impersonal it all is and how apparently unsupervised, or perhaps I should say how unattached, so many of the middle group of staff seem to be. At first sight it is quite logical to think this is a good enlightened thing to have happened. One often hears that this approach gives young people confidence and enables them to get on quickly. However, when you do occasionally come upon a really modern set-up, that still maintains extreme personal leadership, as I happened to do about 18

months ago, you see something of the real "divine spark" throughout the whole organisation which is indefinable yet helps tremendously to make a Works "tick".

When I went to "The First 35 Dinner" in 1960 and met again some of the splendid band of fellows who are now working for Bristol Siddeley Engines, I felt more sure than ever that the leavening effect on young people by early contacts with the "old brigade," who have built up the tradition of "nothing but the best will suffice" is extremely important.

I believe the training and bringing on of a new generation of technicians and technologists for the production of aero-engines is even more important today than ever before. The gas turbine of today lends itself to more specialised calculation than the piston engine, nevertheless it has to be turned into hardware which must work satisfactorily. The younger generation of technical people who, I believe, are on the whole better trained, are sometimes apt to believe that doing the sums is the one and only thing of importance to create a new engine. It is here that the older people can be of great help by virtue of their wide experience as, in the final analysis, the gas turbine is a matter of good mechanical engineering.

I was impressed with the fine new Technical College built at the bottom of Rodney Hill and opened by Sir David Eccles four or five years ago. I was pleased to be invited to the opening and to hear that the royalties received from the Government for the Shadow Industry manufacture during the war had played a large part in this new erection. I sincerely hope that the same interest in the rising generation is still uppermost in the minds of the leaders of the Engine Department and that its executives take a regular part in the policy of training, and the selection of the apprentices.

A sound school of thought on design build-up and the carrying on of management succession is, in my view, a most important subject, and one which I believe pays handsome dividends in a works organisation such as Bristol Siddeley Engines. A senior Training and Research Director can with advantage be set aside for this kind of effort, obviously not to plan the actual design of new engines, but to co-ordinate and balance the supply of enough traditional and highly trained technical men at the right time, to meet increased demand on the design organisation. His duties might also include the following up and co-ordination of patents at the right level and a number of kindred matters, all of which need continual attention and a mature engineer.

The needs of Quality Control, the feeling of the reliability concept generally, and the practice of a Model Room procedure to support the various facets of high-class production, quite apart from the routine inspection built on A.I.D. tradition are most desirable. All of these played an important part in our early days in the Engine Department, chiefly under the able direction first of Burgoine and then of Nourse. These facets of quality management, I am told by Frank Nixon who helped me considerably in instituting such matters at Bristol and is now himself Quality Manager with Rolls-Royce, are receiving a tremendous amount of attention in America both in aircraft gas turbine factories and Nuclear Reactor plants. He has recently returned from attending a Conference in America to discuss these matters alone.

Several similar ideas, which were revolutionary in my day, we introduced in a very simple "reading without tears" way, but sometimes these produced spectacular results. I am sure we could not have accomplished even what we did without them.

In my attempt to review early history I have constantly been reminded of how we could have done better and of some of the wrong decisions that were made. But to dwell on this aspect of history, except as may benefit the future, would be fatal, I can only hope that these reminiscences may spark off fresh ideas to the present generation, and encourage them to put out just that little extra effort that can so easily win the day.

In conclusion, I should like to say how grateful I am for the help so freely given me, both from present members of Bristol Siddeley Engines and also from those who, like myself, have left. I have indeed gained a great deal of pleasure from giving this Lecture but realise how inadequate the effort is, and that it would take many months of research to do justice to this enthralling subject.

The Royal Aeronautical Society
The First Fifty Years

BY

J. LAURENCE PRITCHARD, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S.

1868—The First Aeronautical Exhibition

"A sea of glass like unto a crystal"

The year 1868 was destined to be memorable and significant in the history of the Society. It was the year in which the first Aeronautical Exhibition in the world was held.

The *Mechanics Magazine* for 7th February 1868 said:

"The objects for exhibition," quoting from a circular issued by the Society, "and for which prizes will be offered out of the funds now raising, are light engines and machinery, complete working apparatus, models (working and stationary), plans and drawings, articles of interest commemorating previous experiments, kites or other similar apparatus proposed to be used in cases of shipwreck, traction, or in the attainment of other useful ends; paintings of landscapes and cloud scenery observed from a balloon."

At the February meeting the Council agreed to the appointment of Mr. James Ward of the Customs House, New York, as agent and American Secretary for the purpose of the Exhibition. His application was impressively backed. This was the first time that the Society had acted in conjunction with an American citizen for aeronautical purposes.

The proposed Exhibition attracted considerable attention from all quarters of Great Britain, as well as from abroad, and proved an excellent advertisement for the Society, although an ephemeral one. The Minutes of the Council reveal that Council members and others gave guarantees against loss, and that a number of non-members offered money prizes, particularly for a light engine. These offers enabled the Society to announce a first prize of £100, a considerable sum of money in those days.

The forthcoming Exhibition roused much enthusiasm for the lecture meetings of the Society. In addition to the Spring meeting held on 25th March, three special evening meetings were held, during the twelve-day run of the Exhibition, all at the Society of Arts.

The first paper, by John Heath, proposed that a balloon should be fitted with a circular plane which could be inclined to the horizontal and, by a difference of air flow between the plane and the balloon, as it ascended or descended, provide a force to enable the balloon to be steered to some extent. A similar idea had been put forward by John Evans over fifty years previously, and discussed by Sir George Cayley in the *Philosophical Magazine* for February 1816. It was rightly condemned by Wenham.

The next paper, by D. S. Brown, one of the members of the Exhibition Committee, was much more to the taste of the audience and its Chairman, for it was to show "that for sustaining a body in the air by mechanical action more depends upon the application of power than its actual amount." As the Man Power Group of the Royal Aeronautical Society are finding in this present year!

The next paper was by an engineer of some standing, A. Alexander, a member of Council. He was the general manager of the Camel Steel works at Sheffield. The title of his paper was "Power in relation to weight in Aerial Navigation."

In the course of his lecture he gave the explanation why so many who calculated, on theoretical grounds, the power required to fly, greatly over-estimated it. But he drew himself some remarkable conclusions, based primarily on bird flight experiments.

"The results seem to indicate a necessity for a motor, with all accessories, not exceeding from 80 to 150 lbs. weight per horse power. On the whole I arrived at the conclusion that with a power of one horsepower for every 112 lbs. of weight, aerial navigation in the true sense ought to be possible."

At the time Alexander lectured, the lightest engine with accessories weighed considerably more per horsepower. Wenham, in the discussion, stated that he had calculated that the horsepower of a pelican was 1/11, about half that of a man for continuous work.

Some excitement was caused by Wenham's announcement that a Mr. Charles Spencer "has within the last few weeks succeeded in making short flights in a machine of his own invention and construction, and entirely by muscular force . . . . Mr. Spencer hopes to give personal demonstrations at our forthcoming Exhibition."

Spencer's machine was a glider and during one of the lecture meetings held at the time of the Exhibition he told a number of members he was going to fly that afternoon. The glider was made on the principle of a boy's dart and "consisted of a long wedge-shaped aeroplane with an under web or keel set vertically. This was combined with two short wings moved by the arms. By a preliminary quick run the inventor has been able to take short flights to the extent of 160 feet," so ran the Exhibition catalogue.

Spencer himself declared he had made a flight of between 120 and 150 feet, only a fortnight before the meeting, at Potter's Bar, "in the open air, running down a little hill."

It may be noted here that at a lecture meeting of the Society, held two years later, Spencer gave a further account of his experiments. In the course of the discussion he declared that the total surface was 135 sq. feet and the structure weight 24 lb. His own weight was 140 lb. giving a wing loading of just over a pound a square foot. But I have been unable to find any confirmation of his statements.

Many at that time were becoming aware of the possibility of using a fixed surface for flight, but it is astounding that more experiments were not carried out with curved surfaces.

At this meeting a model engine maker, living in Manchester, Mr. Artingstall, sent a communication to the

Society, from which, being a mathematician, I must quote. It has taken many years to live his words down. He was discussing the problem of flight.

"It is beyond the power of mere college or school mathematicians, however profound, and can only be dealt with by the experimental philosopher, that is, a man who can put into practice his mathematical theories. A Newton, a Watt or a Faraday has not yet appeared in aeronautics."

How Mr. G. H. Bryan, with his caustic wit, would have answered that one! Artingstall, like Henson, had at one time written to Sir George Cayley about his experiments.

The *Mechanics Magazine*, which faithfully in the early years of the Society reported its meetings, ended the report of this first meeting of 1868,

"This closed the business of the evening, when the President remarked that the next meeting would be at the Crystal Palace. The Society had provided refreshments for the members and their friends, who agreeably passed the remainder of the evening in conversation."

Nowadays refreshments are served *before* the meeting —perhaps it is as well. And an agreeable conversation has degenerated into that monotonous subject, "Shop."

In between the March meeting and the meetings held during the Exhibition, interest in the possible future increased. On 17th April 1868 the *Mechanics Magazine* published a paper, one of many, serious or frivolous or fantastic, which appeared that year. Aviation could still be laughed at and aviation enthusiasts of those days were well aware of the laughter.

"The editor of an American paper," (wrote the anonymous writer under the title of "Aerial Locomotion") "a short time ago imagined the present century to have passed away, and portrayed the state of Society in 1960-1970.

"A lady is entertaining a few friends just before dinner, and she tells them they will not have long to wait—her husband has only gone to pay a visit in the neighbourhood of 'Boothia' and she expects his return from the North Pole every minute! Wonders will never cease, and considering the earnest way in which the Aeronautical Society is going to work, we should not be at all surprised to learn that travelling by air would soon become as easy and as regular as travelling by land or by water . . . .

"It appears to us that for aerial navigation, instead of using screws and paddles as in steamers, or cylinders and pistons as in locomotives, it might be as well to condense the air by means of chemical agency, and then to force it in concentrated quantities against the circumambient atmosphere, preventing as much as possible its diffusion . ."

Jet propulsion!

Three meetings were held during the period of the Exhibition. At the first meeting, on 29th June, Glaisher startled those present by announcing that M. Delarmarne, who had offered to ascend from the Crystal Palace on the previous Saturday, had deliberately deceived him. He had, in fact, led the Society to believe he was going to ascend in a normal balloon, filled with coal gas, or hydrogen. It turned out to be a balloon, on the principle of the hot air balloon of Montgolfier, filled with vapour from benzine! Some eighteen tins filled with liquid benzine supplied the fuel. As can easily be imagined, there was a sudden blaze when the benzine was lighted, and the balloon was destroyed. The balloon ascent had been advertised as one of the attractions of the Exhibition, enabling members to make ascents!

The muddle-headed Mr. Heath, who had already lectured on a method of guiding balloons, again put forward the balloon as the flying machine of the future and stated boldly, "We conclude that no object will ever be long sustained in the air which is not lighter than that element." He continued, "the assertion compels us to face the mystery (as yet unexplained) of the flight of birds . . . . It may continue a mystery for many years to come."

Heath's statement was promptly challenged by Thomas Moy.

"Few would agree with Mr. Heath," he declared . . . . "If a thing moved slowly through the air, there is no perceptible pressure, but if it moved fast, there is immense pressure. The pressure of the air increases as the square of the velocity; . . . He would ask them to think of nothing less than 150 miles an hour, *as speed would gain the day, and nothing less than that speed.*"

It was, for that time, a bold, imaginative statement; Wenham and other speakers agreed with Moy. E. W. Young, a member of the Society and of the Institution of Civil Engineers, urged that the Society should "devote some of their energies to experimental operations, in order to enable them to obtain data on which to construct machines . . . . as little consideration would show that the curved surface is better than the true plane. The bellying of canvas, for example, gave the hollow form."

There had been many experiments to measure the pressure on flat planes, but the variation of the results did not inspire much confidence, and Glaisher from the Chair declared "The different results found only showed the absolute necessity for carrying out the suggestions of Mr. Young."

The seeds of aeronautical research were being sown by members of the Society. Wenham, indeed, had already been considering the form of apparatus to obtain the best results and drew attention, at the next meeting on 1st July, to the importance of the experiments of a previous speaker, J. M. Kaufman, a member of the Institution of Civil Engineers, showing that the effect produced on one area will not be produced on another and that aeronauts might be basing their calculations and wasting their time with data that were entirely wrong.

Thomas Moy, who spoke at the second Exhibition meeting, when discussing density, used a phrase which ought to go down in aeronautical history. He was discussing a globe for assisting a diver to rise to the surface and said, "If he could get a round thing and *fill it full of emptiness*, he would rise in the water." The italics are mine. Wenham, in the course of the discussion, made the interesting revelation that he had tried to fly under his own power. "In the experiments I have always, up to the present time, failed to raise myself in a calm, but in a twenty mile an hour wind I could raise myself without difficulty. In fact, the last experiments I made were dangerous."

John Stringfellow attended the meeting and referred to his triplane, then being exhibited at the Crystal Palace, his experiments with Henson on Bala Down, and his own model of 1848.

Some seventy-seven items were listed in the Exhibition catalogue and over £300 in prizes was offered.

The Jurors' Report showed some fifteen engines competing for the £100 prize offered for the lightest engine. Seven "were to be worked by gas or explosive materials. None of these were shown in motion, and in some cases their action was not explained by their inventors . . . . thus leaving no other motive powers to be decided upon but 'Steam engines'." Of the steam engines, two had no boilers and three others were not shown in motion. And then there were three little light engines! Two were shown by John Stringfellow and one by Camille Vert of Paris, well known for his 'flying fish' dirigible. This latter model was

used, indeed, for propelling a model airship, and was very successful in doing so, "but the model was too small to enable any accurate test to be applied for ascertaining the power."

I give the full report of the Jury on Stringfellow's engine which won the £100 prize.

> "The Engine No. 4, by Stringfellow, from its size and power may be considered something more than a mere model. The cylinder is 2 in. in diameter, stroke 3 in. and works with a boiler of 100 lbs. per square inch; the engine making 300 revolutions per minute. The time of getting up steam was noted; in three minutes after lighting the fire the pressure was 30 lbs., in five minutes 50 lbs., and in seven minutes there was a full working pressure of 100 lbs. When started the engine had a fair amount of duty to perform in driving two four-bladed screw propellers 3 ft. in diameter at 300 revolutions per minute.
>
> "The data for estimating the power are taken as follows—area of piston 3 in., pressure in cylinder 80 lbs. per square inch, length of stroke 3 in., velocity of piston 150 ft. per minute, $3 \times 80 \times 150 = 36{,}000$ foot pounds; this makes rather more than one horsepower (which is reckoned as 33,000 foot pounds). The weight of the engine and boiler was only 13 lbs. and is probably the lightest steam engine that has ever been constructed. The engine, boiler, car and propellers together, were afterwards weighed, but without water and fuel, and were found to be 16 lbs."

A letter in the possession of the Society, written by Stringfellow's niece to her aunt, and dated 2nd July 1868, is revealing of the interest taken in Stringfellow's engine and triplane.

"It was a grand day for uncle. The Prince and Princess of Wales and Prince Alfred, and several of the Princesses with their train and attendants were there. The Prince was so charmed with the model that he sent the Duke of Sutherland for uncle to go to the Royal box . . . . Uncle has won the prize . ."

Alas, that was the end of John Stringfellow's appearance on the public stage of fame, and practically the end of his work. He was then within a few months of sixty-nine, and suffered badly from rheumatism. Brearey kept up correspondence with him until within two years of his death at the great age of 83.

The son, F. J. Stringfellow, ultimately sold the prize engine to Professor Langley, Secretary of the Smithsonian Institution, where it is now one of America's precious exhibits.

Of the aeroplane exhibits there was inevitably shown two to illustrate how man could fly under his own power. One by Charles Spencer, which has already been referred to, and the other by W. Gibson, a flapping wing one, which failed after one flap!

The Duke of Argyll also showed a flapping wing model. He had the foresight to use a real pair of birds' wings, rigidly attached to a clockwork mechanism to make them flap. The model was shown travelling along a horizontal wire for the benefit of those attending the Exhibition.

Two of the interesting exhibits were helicopter models. The first, by Viscount Ponton d'Amecourt, consisted of a steam engine with an aluminium boiler, driving contra-rotating horizontal airscrews. The Jurors' Report notes, "Though a mere perpendicular ascent alone is not required, yet by inclining the screws more or less from the vertical direction, a quick horizontal speed would be the result."

The other was that of W. H. Phillips.

> ". . . . a working model of an Aerial Machine, raising and sustaining itself in the air for several minutes, being worked by a power evolved by the combustion of materials similar to those used in the original Fire Annihilator, steam and gaseous products being intermixed within the boiler and forced at high pressure into a rotary engine, turning, lifting or driving fans. The model machine weighs only a few pounds, and by raising and sustaining itself in the air is to demonstrate the practicability of raising heavier weights and effecting aerial transit at a high speed in any direction."

No demonstration was made of the model, but the Jurors were so impressed by Phillips' ideas that they printed in the Report his own account of his experiments.

> "More than 25 years ago," asserted Phillips, "I made my first experiments with model Aerial Machines, and not knowing what had been attempted by others, I adopted revolving fans as the most promising form of wings. The apparatus was made entirely of metal weighing when charged about 2 lbs. and of a size that could be contained in a hat box. The distance travelled was across two fields, where, after a long search, I found the machine, minus the wings, which had been torn off from contact with the ground.
>
> "The experiment gave me great delight, believing, as I did, that the problem of flight by inanimate power was partially solved, and I have since pursued the study of mechanical aerostation with the idea that the subject is one of the very highest importance to civilised nations."

W. Quartermain showed an ingenious engine: "the motive power is a species of rocket composition, the gases resulting from the ignition of which give motion to a piston. All danger of explosion is avoided by introducing limited quantities only, to be ignited at one time through self-closing valvular chambers."

This brief description from the Jurors' Report savours very much of a primitive internal combustion engine.

The outstanding model at the Exhibition was, like the prize engine, the work of Stringfellow, a triplane which ran along a wire stretched across the transept of the Crystal Palace.

The model was remarkable for the elegance and neatness of its construction, and was the first experiment adopting the proposed system of superposed aeroplanes to a steam flying machine.

There were a number of minor exhibits. Monsieur Begue showed a pair of wings fixed to a rotating axle. By means of a cam the wings were made to expand in the descent and close in the ascent, like a duck's foot when swimming. Numerous drawings and diagrams of proposed flying machines were shown and a number of small cardboard models which did not call for any comment. In the last section of the Exhibition a number of kites, including J. E. Cordner's man-lifting kites for saving lives of shipwrecked mariners, were shown. During the whole time of the Exhibition, there was no wind to fly and test any of the kites, or Cordner might possibly have been the first man to be raised in the air by the pressure of the wind on a surface.

The Exhibition lasted eleven days, from 26th June to 5th July, and proved a financial failure. The guarantors had to be called upon to make up the deficiency, between £40 and £50.

The Jurors, in a note following their detailed report, said, "It remains now to be considered how far the Exhibition has forwarded the science of Aeronautics. With respect to the abstract question of mechanical flight, it may

be stated that we are still ignorant of the rudimentary principles which should form the basis and rules for construction. No one has yet ventured to give a correct experimental definition of the primary laws and amount of power consumed in the flight of birds; neither, on the other hand, has any tangible evidence been brought forward to show that mechanical flight is an impossibility to man."

The Jurors pointed out, indeed, that the figures for pressures on flat planes, which had been obtained by Smeaton* and others, were being challenged by members of the Society.

" For want of similar experiments," added the Report, " we are equally ignorant of the force of the wind exerted on surfaces of various sizes, forms, and degrees of inclination; these are generally *assumed* on the mathematical laws of the resolution of forces, considered as the rigid impulse of inelastic weight and matter, and demonstrated by the aid of diagrams combined with a system of weights, cords and pulleys, which convey but a very distant idea, relative to the conditions of the present inquiry, where the elastic and yielding nature of the air is the cause of such unforeseen results, differing in accordance to the width, form, angle, and speed of the surface of impact."

The Exhibition had drawn public attention to the necessary data which must be obtained and experiments which must be carried out before any practical flying machine could be successfully built. F. H. Wenham, James Glaisher, Sir William Fairbairn and A. Alexander, members of Council, were particularly aware of the possibilities, and the steps to be taken, although it was not until the following year that they initiated the first series of experiments which were to become historical.

The *Mechanics Magazine* reported the opening of the Exhibition: " Whatever doubt may have been felt as to the possibility of forming anything like an attractive aeronautical exhibition in London is certainly more than dissipated by the present show. In this respect, to commence with, it is a decided success, and might have been still greater had the Aeronautical Society possessed means which would have enabled them to give their proceedings greater publicity and to make their intentions more widely known. But the Exhibition bears evidence of a large amount of careful thinking and working upon a very special subject . . . .

" There is a general expectation that the Exhibition will be repeated next year, upon a much grander scale than the present: this idea is warranted by the great encouragement the Society has received in its first attempt. Such being the case we cannot be considered premature if we call the attention of those who wish to become guarantors, or to offer prizes, to the fact."

" We confess ourselves to be less sanguine of ultimate success than many who have toiled at the question for years . . . But then the subject is in its infancy as regards the practical bearing upon the question of aerial flight and the Aeronautical Society could have taken no better step for its advancement and development than the one they have—the promotion of an aeronautical exhibition."

French comment was not wholly favourable. W. M. Fonvielle, in *La Liberté* of July 1868, wrote:

" The exhibition is in two sections. The first shows power machines to compete with balloons, on which the advocates of the heavier-than-air machines have sung a *de profundis*.

" I have looked in vain for any movement in these renowned machines which ought to enable us to fly like the eagle or at least compete with the vulture. I have only seen a very small number of unorganised objects which have never left the ground and now are sentenced to complete rest. So one is not able to say what Galileo said of the world ' And yet it moves! ' Among the exhibits are several model dirigibles which ought to be filled with hydrogen. One or two exhibits have wings borrowed from a swan or may be goose. Another proudly showed four wings patterned on the bat. Finally, there were kites which are a delight of children. Yet I doubt that instead of carrying an aeronaut into the clouds there is enough power to take up a cat! "

De Villeneuve, editor of *L'Aéronaute*, reported the Exhibition in considerable detail, spread over many months of his journal. In the July 1868 issue he wrote " The English papers are much better than ours as regards hoaxes, puffs and claims. The fairy tales put out about the Aeronautical Exhibition reached colossal proportions."

Villeneuve was a very energetic experimenter himself in later years, and a still more energetic upholder of French efforts to advance the cause of aeronautics.

*The data were obtained by Rouse, not Smeaton.

REFERENCES

Annual Reports, 1867-68; Catalogue of the Exhibition at Crystal Palace, 1868, and the Jurors' Report; Minutes of Council, 1867-68; correspondence of the Society; *Mechanics Magazine*, 1868; *La Liberté*, July 1868; *L'Aéronaute*, 1868; *Journal of the Royal Aeronautical Society*, June 1956.

TECHNICAL NOTES

An Iteration Process for the Solution of the Prandtl-Meyer Expansion

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1. Introduction

In the *Journal of the Royal Aeronautical Society*, November 1959,[1] the writer described an iteration process for the solution of the equations for plane oblique shock waves. Iteration methods avoid the difficulty of reading a solution from a chart; or, given a chart, provide a means of checking such a reading and, usually, of improving the accuracy to any desired degree.

As with plane oblique shocks, it is usual to use a chart to obtain the solution of a problem involving a Prandtl-Meyer expansion fan. The present note proposes an iteration process to avoid the use of a Prandtl-Meyer chart; or, given such a chart, offers the possibility of improvement in the accuracy of the solution obtained by reading from it, the limit being set by the accuracy of the trigonometric tables used.

We state the solution of the Prandtl-Meyer equations in the form

$$\lambda \tan \omega = \tan \lambda (\omega + \delta), \quad . \quad . \quad (1)$$

where as usual

$$\lambda^2 = \frac{\gamma - 1}{\gamma + 1}.$$

In equation (1) ω is the complement of the Mach angle, *i.e.*

$$\cos \omega = M^{-1} \quad . \quad . \quad . \quad (2)$$

and δ is the angle between the direction of flow at Mach number M and the direction of flow corresponding to $M=1$. (*See* Fig. 1.) Thus, if we have a flow at Mach number M_1 which is expanded at a corner to a Mach number M_2, then

$$\left.\begin{aligned} \lambda \tan \omega_1 &= \tan \lambda (\omega_1 + \delta_1) \\ \lambda \tan \omega_2 &= \tan \lambda (\omega_2 + \delta_2) \end{aligned}\right\} \quad . \quad . \quad . \quad (3)$$

and the flow deflection is $\delta_2 - \delta_1$. If the two Mach numbers are given, the deflection can be found explicitly from (1) and (2); we use (2) to find ω_1 and ω_2 from M_1 and M_2 and then apply (1) in the form

$$\delta = \frac{1}{\lambda} \text{ arc tan } (\lambda \tan \omega) - \omega \quad . \quad . \quad (4)$$

to give δ_1 and δ_2 directly. However, it is more usual to be given M_1 and the deflection $\delta_2 - \delta_1$, and to be required to find M_2: this requires the solution of equations (3) for ω_2.

With $\gamma = 1{\cdot}4$ and $\lambda^2 = \dfrac{1}{6}$, (4) is then

$$\delta = \sqrt{6} \text{ arc tan } \left(\frac{\tan \omega}{\sqrt{6}}\right) - \omega. \quad . \quad . \quad (5)$$

Received 3*rd February* 1961.

2. The iteration formula

Given the angle δ, we can solve equation (1) for ω by the iteration process

$$\lambda \tan \theta_{n+1} = \tan \lambda (\delta + \theta_n) \quad . \quad . \quad (6)$$

with θ_0 arbitrary. Then as n increases,

$$\theta_n \longrightarrow \omega.$$

The convergence of the process (6) is established later (Section 3). However, while (6) is the formal statement of the process, it can be conveniently modified to a form giving the Mach number directly. By squaring (6) we obtain

$$\lambda^2 (\sec^2 \theta_{n+1} - 1) = \sec^2 \lambda (\delta + \theta_n) - 1,$$

and writing $\cos \theta_i = m_i^{-1}$ (c.f. (2)),

$$m_{n+1}^2 = \left(1 - \frac{1}{\lambda^2}\right) + \frac{1}{\lambda^2 \cos^2 \lambda (\delta + \text{arc cos } m_n^{-1})} \quad . \quad . \quad (7)$$

In this form, the iteration proceeds directly to the square of the required Mach number M. It is possible to write the formula more elegantly in terms of tangents or secants, but since reading from trigonometric tables is required, it has been written in terms of cosines, which are much easier to read at angles approaching $\pi/2$.

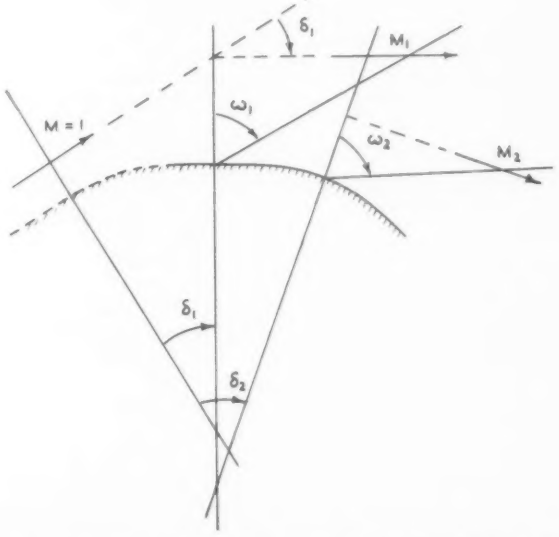

FIGURE 1. Co-ordinate system. Normal to direction of flow corresponding to $M=1$ is origin for angles δ, $\omega+\delta$.

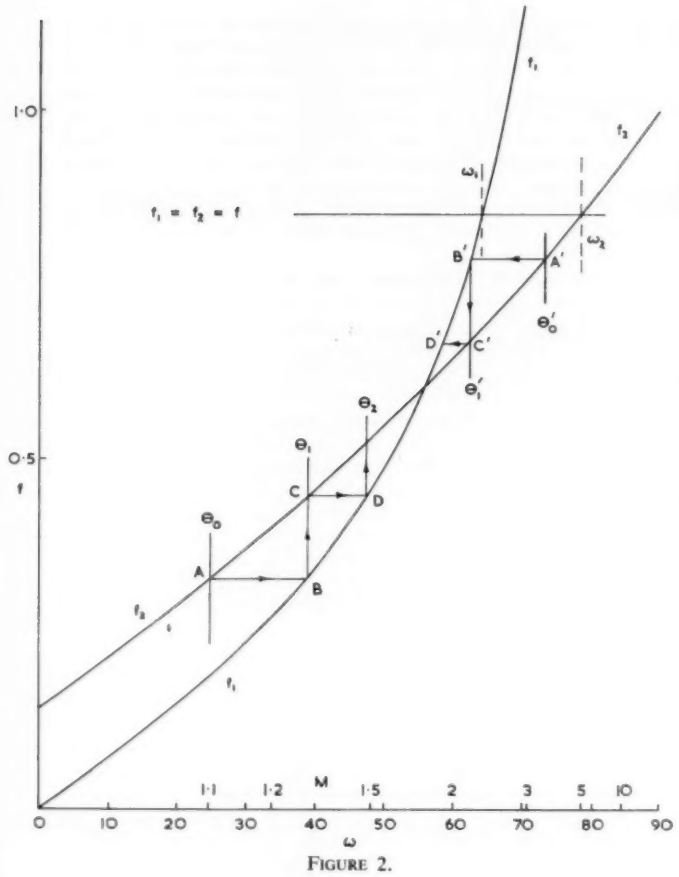

FIGURE 2.

As before, if $\lambda^2=\frac{1}{6}$, we find the numerical form of (7) to be

$$m_{n+1}{}^2=-5+6/\cos^2\left(\frac{\delta+\arccos m_n{}^{-1}}{\sqrt{6}}\right), \qquad (8)$$

and the corresponding form for δ is

$$\delta=\sqrt{6}\arccos\sqrt{\left(\frac{6}{M^2+5}\right)}-\arccos\frac{1}{M} \quad . \qquad (9)$$

3. CONVERGENCE OF THE ITERATION PROCEDURE

In Fig. 2 are plotted against ω the two functions appearing in (1), namely,

$$f_1=\lambda\tan\omega, \quad . \quad . \quad . \qquad (10)$$

$$f_2=\tan\lambda(\delta+\omega). \quad . \quad . \qquad (11)$$

For definiteness in Fig. 2 the values $\lambda=1/\sqrt{6}$ and $\delta=20°$ have been used; however, the curves are typical of any practical case, in which

$$0<\lambda<1; \quad 0<\delta<\left(\frac{1}{\lambda}-1\right)\frac{\pi}{2}. \quad . \qquad (12)$$

It will be noted that f_1 and f_2 are related by an affine transformation: if f_1 and ω are both multiplied by λ and the origin moved in the negative sense by $\lambda\delta$, then (10) becomes (11). The intersection of f_1 and f_2 determines the value of ω corresponding to the chosen δ.

By differentiation of (10) and (11) we find

$$\frac{df_1}{d\omega}=\lambda\sec^2\omega=\lambda\left(1+\frac{f_1{}^2}{\lambda^2}\right), \quad . \qquad (13)$$

$$\frac{df_2}{d\omega}=\lambda\sec^2\lambda(\delta+\omega)=\lambda(1+f_2{}^2). \quad . \qquad (14)$$

Accordingly, if we draw any horizontal straight line cutting both curves in $f_1=f_2=f$, and if the corresponding values of ω are ω_1, ω_2, we have from (13), (14), since λ^2 is less than unity,

$$\left(\frac{df}{d\omega}\right)_1>\left(\frac{df}{d\omega}\right)_2>0. \quad . \quad . \qquad (15)$$

Now it is clear from what has been said of the affine relationship between f_1, f_2, that (10), (11) must intersect at least once in the range $0<\omega<\pi/2$ (provided δ satisfies (12)). Moreover, we deduce from (15) that only one intersection is possible; for if we make a positive increment in f when the line f is above the intersection, $\delta\omega_2>\delta\omega_1$: the curves therefore continually diverge as f increases. Similarly, below the intersection, the curves again continually diverge as f decreases. Thus there can be only one intersection; and (15) holds there as elsewhere.

We now examine the iteration process (6). It begins with an arbitrary θ_0; suppose first $\theta_0<\omega$, the required solution. Insertion of θ_0 in the right-hand side of (6) determines $f_2(\theta_0)$—point A in Fig. 2. The relation $f_1(\theta_1)=f_2(\theta_0)$ is now used to find θ_1 at point B. Next, this gives $f_2(\theta_1)$ at C and hence $f_1(\theta_2)$ at D, and so on. Since the curves have positive slopes, all the increments in f and θ must be finite and positive until the curves intersect, and at any stage

$$\theta_n<\theta_{n+1}<\omega.$$

Similarly, if we begin with $\theta'_0>\omega$ we follow a path $A'B'C'D'\ldots$; in either case the process converges to ω.

4. SOME EXAMPLES

The process described connects three quantities, M_1, M_2, and the deflection $\delta_2-\delta_1$. Given any two, the third may be found. Most usually, one is given M_1 and the deflection and is required to find M_2: this problem is exemplified in (*i*) below. However, it is also sometimes necessary to find M_1, given M_2 and the deflection; example (*ii*) illustrates this. For completeness, example (*iii*) illustrates the derivation of $\delta_2-\delta_1$ from given M_1, M_2, though here no iteration is necessary, as stated earlier.

(*i*). Air flowing at Mach number $M_1=2$ is expanded round a corner which deflects it by 15°. What is the new Mach number M_2?

We first use (9) to find δ_1 corresponding to $M_1=2$. We have, with all angles in degrees

$$\delta_1=\sqrt{6}\arccos\sqrt{\frac{6}{9}}-\arccos\frac{1}{2}$$

$$=\sqrt{6}\,(35{\cdot}26)-60$$

$$=26{\cdot}38.$$

Since $\delta_2-\delta_1=15$, we have

$$\delta_2=41{\cdot}38.$$

Hence (8) becomes

$$m_{n+1}{}^2=-5+6/\cos^2\left(\frac{41{\cdot}38+\arccos m_n{}^{-1}}{\sqrt{6}}\right).$$

TABLE I

(1) m_n	(2) arc cos m_n^{-1}	(3) 41·38+(2)	(4) (3)/$\sqrt{6}$	(5) cos (4)	(6) m_{n+1}^2	(m_{n+1})
2	60	101·38	41·39	0·7502	5·661	(2·38)
2·38	65·15	106·53	43·49	0·7255	6·447	
2·54	66·82	108·20	44·17	0·7173	6·661	
2·59	67·29	108·67	44·36	0·7150	6·737	
2·60	67·38	108·76	44·40	0·7145	6·752	
2·598	67·36	108·74	44·39	0·7146	6·749	2·598

By way of illustration, we begin with $m_0=2$, although we know that the final value must considerably exceed this. We then have the results shown in Table I.

Table I has been derived by rounding off m_n upwards to two decimals, except in the last line. In practice, it is obvious that the process can be much shortened by a good first guess and intelligent approximation: thus one might begin with a guess at $m_0=2{\cdot}5$; then $m_1=2{\cdot}57$: but one would round off upward to 2·60 and find this almost correct.

It is difficult to read a table of cosines to greater accuracy than is implied in the last line; however, the accuracy obtained is far greater than is possible in reading from a chart. Fig. 3 shows the usual chart of δ against M found from (9), which can be used to obtain a first approximation.

(*ii*). An airstream has been expanded to $M_2=3{\cdot}5$ round a 20° corner. What was the initial Mach number M_1?

From (9) we have from the given M_2

$$\delta_2=\sqrt{6}\arccos\sqrt{\left(\frac{6}{17{\cdot}25}\right)}-\arccos\frac{1}{3{\cdot}5}$$
$$=\sqrt{6}\,(53{\cdot}86)-73{\cdot}40=58{\cdot}53.$$

Since $\delta_2-\delta_1$ is 20, we have

$$\delta_1=38{\cdot}53.$$

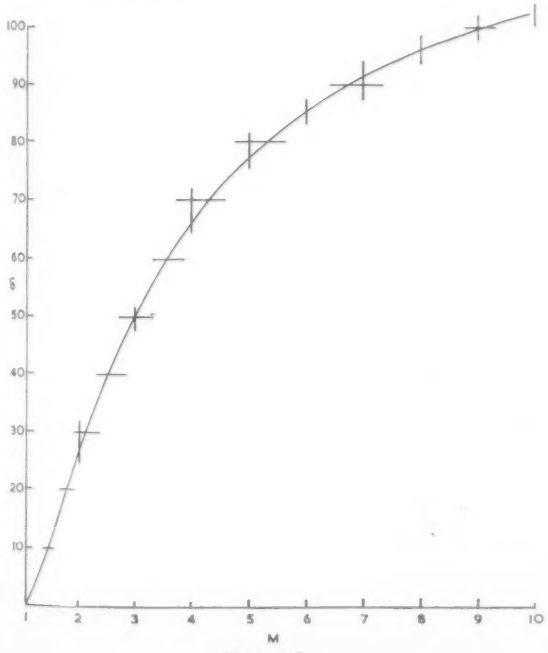

FIGURE 3.

Accordingly, M_1 is determined by the solution of

$$m_{n+1}^2=-5+6/\cos^2\left(\frac{38{\cdot}53+\arccos m_n^{-1}}{\sqrt{6}}\right).$$

We could use the chart of Fig. 3 for a first approximation. However, we guess here $m_0=2{\cdot}5$. The iteration procedure gives $m_1=2{\cdot}477$; we round off to $m_1=2{\cdot}47$ and repeat finding $m_2=2{\cdot}474$; round off to $m_2=2{\cdot}475$ which repeats. Thus $M_1=2{\cdot}475$.

(*iii*). What is the deflection of an airstream expanded from $M_1=1{\cdot}2$ to $M_2=2{\cdot}6$?

This requires only a double use of (9).

Then

$$\delta_1=\sqrt{6}\arccos\sqrt{\frac{6}{6{\cdot}44}}-\arccos\frac{1}{1{\cdot}2}=3{\cdot}56.$$

$$\delta_2=\sqrt{6}\arccos\sqrt{\frac{6}{11{\cdot}76}}-\arccos\frac{1}{2{\cdot}6}=41{\cdot}43.$$

Hence $\delta_2-\delta_1=37{\cdot}87$ degrees.

5. Completion of the Solution

As a general rule, it is required to find not only the Mach number M_2, given M_1 and the deflection, but also the corresponding pressure and perhaps temperature and density. For this purpose, since the flow is isentropic, we employ the ratio

$$r=\frac{M_1^2+2/(\gamma-1)}{M_2^2+2/(\gamma-1)}$$
$$=\frac{M_1^2+5}{M_2^2+5}$$

for $\gamma=1{\cdot}4$.

Now the iteration procedure yields incidentally the quantity (*see* (7))

$$m_{n+1}^2+\left(\frac{1}{\lambda^2}-1\right)=m_{n+1}^2+\frac{2}{\gamma-1}$$

which converges to the denominator of r. Thus r is determined, and then

$$\frac{p_2}{p_1}=r^{\frac{\gamma}{\gamma-1}},\qquad\frac{\rho_2}{\rho_1}=r^{\frac{1}{\gamma-1}},\qquad\frac{T_2}{T_1}=r.$$

As an illustration, let us complete the solution of the problem of Section 4 (*i*). Here $M_1^2+5=9$, and the iteration converges to $M_2^2+5=11{\cdot}749$. Thus

$$r=0{\cdot}766,$$

and with $\gamma=1{\cdot}4$

$$\frac{p_2}{p_1}=0{\cdot}393,\qquad\frac{\rho_2}{\rho_1}=0{\cdot}514,\qquad\frac{T_2}{T_1}=0{\cdot}766.$$

REFERENCE

1. COLLAR, A. R. (1959). Iterative Solutions of the Equations for Plane Oblique Shock Waves. *Journal of the Royal Aeronautical Society*, November 1959.

The Approximate Calculation of Eigenvalues for Certain Second-Order Linear Differential Equations

W. J. GOODEY, A.F.R.Ae.S.

IN A RECENT TECHNICAL NOTE, Squire[1] discussed the approximate solution of certain second-order linear differential equations by the method attributed variously to Riccati, Madelung, Wentzel, Kramers and Brillouin (the W.K.B. method), and others. The problem of eigenvalues, frequently met with in this type of equation, does not, however, appear to have received much attention by this method, and in this note a simple formula is developed which appears to give excellent numerical results in many cases.

Let the differential equation be of the form

$$y''+\{\lambda^2\beta^2(x)+\gamma(x)\}\,y=0. \quad . \quad . \quad (1)$$

We assume that $\beta^2(x)$ does not become zero in the given range of x. Thus we can take $\beta(x)>0$. It is required to find non-trivial solutions of this equation satisfying boundary conditions of the type $Ay+By'=0$ at each end of the range of integration, where A and B are constants not involving the parameter λ. In general, such solutions exist for an infinite set of discrete values of λ, which we shall assume to be real.

Making the Riccati transformation $y=\exp.\int_0^x \phi(x)\,dx$, equation (1) transforms to

$$\phi^2+\phi'+\lambda^2\beta^2(x)+\gamma(x)=0. \quad . \quad . \quad .(2)$$

Evidently there is no loss of generality if the lower limit of integration is taken to be zero.

A first approximation to the solution of equation (2) is $\phi=\pm i\lambda\beta$, and a slightly better approximation is easily shown to be

$$\phi=\pm i\lambda\beta-\frac{\beta'}{2\beta}. \quad . \quad . \quad . \quad . \quad (3)$$

From equation (3) we obtain an approximate solution of equation (1) in the form

$$y=K\beta^{-\frac{1}{2}}\exp.\left(\pm i\lambda\int_0^x \beta dx\right), \quad . \quad . \quad (4)$$

leading to the two real linearly independent solutions

$$y=K\beta^{-\frac{1}{2}}\sin\left\{\lambda\int_0^x \beta dx\right\} \text{ and } K\beta^{-\frac{1}{2}}\cos\left\{\lambda\int_0^x \beta dx\right\} \quad (5)$$

From equations (5) we can construct an approximate solution satisfying the given boundary conditions. This solution will be denoted by $y^{(1)}$, and the corresponding value of λ by $\lambda^{(1)}$. For example, if $y=0$ when $x=0$ and $x=l$,

$$y^{(1)}=K\beta^{-\frac{1}{2}}\sin\left\{\lambda\int_0^x \beta dx\right\}, \text{ where } \lambda^{(1)}=\frac{n\pi}{\int_0^l \beta dx}$$

(Generally we are chiefly interested in the lowest mode, $n=1$.) This will usually give only a rough approximation to y and λ, but a much better approximation to λ may be found as follows.

From Rayleigh's Principle, if $y^{(1)}$ is an approximation containing only small proportions (ε) of unwanted modes, the quotient $\lambda^2=-\int_0^l y(y''+\gamma y)\,dx \Big/ \int_0^l \beta^2 y^2\,dx$ has an error of order ε^2 . . . . . (6)

Putting $y=y^{(1)}$, equation (6) leads to the required formula

$$\lambda^2=\lambda^{(1)2}-\frac{\int_0^l\left(\frac{3\beta'^2}{4\beta^2}-\frac{\beta''}{2\beta}+\gamma\right)y^{(1)2}dx}{\int_0^l \beta^2 y^{(1)2}dx} \quad . \quad . \quad (7)$$

It may not be possible to evaluate the integrals in terms of known mathematical functions, but satisfactory results may generally be obtained by numerical integration, using Simpson's Rule, for example, with $0{\cdot}1l$ for the interval of integration. The integral $\int_0^l \beta^2 y^{(1)2}dx$ may, however, be simplified by the substitution $\psi=\int_0^x \beta dx$; for example, if $y^{(1)}=\beta^{-\frac{1}{2}}\sin\left\{\lambda\int_0^x \beta dx\right\}$, $\int_0^l \beta^2 y^{(1)2}dx$ reduces to $\frac{1}{2}\int_0^l \beta dx$.

Note also that $\left(\frac{3}{4}\frac{\beta'^2}{\beta^2}-\frac{\beta''}{2\beta}\right)=\beta^{\frac{1}{2}}\frac{d^2}{dx^2}(\beta^{-\frac{1}{2}})$, which is helpful if $\beta^{-\frac{1}{2}}$ is a simple function of x.

NUMERICAL EXAMPLE

Let the differential equation be $y''+\lambda^2(1+x)^2y=0$, with the boundary conditions $y(0)=y(1)=0$.

In this case $\beta=(1+x)$, and equation (7) becomes

$$\lambda^2=\lambda^{(1)2}-\int_0^l \frac{\sin^2\{\lambda^{(1)}(x+\frac{1}{2}x^2)\}\cdot dx}{(1+x)^3}, \quad . \quad (8)$$

where $\lambda^{(1)}=2/3\pi$. The integral was evaluated by tabulation of the integrand at $0{\cdot}1$ intervals, using Simpson's Rule, whence it was found that

$$\lambda^2=\left(\frac{2\pi}{3}\right)^2-0{\cdot}14109=(0{\cdot}6559\pi)^2.$$

The differential equation can be solved exactly in terms of Bessel functions (*see* Ref. 2), the general solution being

$$y=(1+x)^{\frac{1}{2}}\left[AJ_{1/4}\left\{\frac{\lambda}{2}(1+x)^2\right\}+BN_{1/4}\left\{\frac{\lambda}{2}(1+x)^2\right\}\right].$$

The boundary conditions then lead to the transcendental equation for λ

$$J_{1/4}\left(\frac{\lambda}{2}\right)N_{1/4}(2\lambda)-J_{1/4}(2\lambda)\,N_{1/4}\left(\frac{\lambda}{2}\right)=0. \quad . \quad . \quad (9)$$

Solutions of this type of equation will be found in Ref. 2 (Table XVIII), from which we find $\lambda \frown 2{\cdot}062=0{\cdot}654\pi$. The correction to $\lambda^{(1)2}$ is here only about 3·2 per cent, but equation (8) has been found to give results in satisfactory agreement with theory when this correction was as much as 25 per cent.

REFERENCES

1. SQUIRE, W. (1959). Approximate Solution of Linear Second Order Differential Equations. *Journal of the Royal Aeronautical Society*, Vol. 63, p. 368, June 1959.
2. JAHNKE and EMDE (1933). *Tables of Functions*. Second (revised) Edition, Teubner, Berlin, 1933.

Received 12th October 1960.

THE BRANCHES

The Luton Branch comes into our history in 1942, but the aviation beginnings were in 1914.

LUTON Branch may be one of the younger twigs, but the connections with Aviation date back to May 1914 when the factory of "Hewlett & Blondeau " was established at Leagrave on the site of the present Electrolux Factory. The "Omnia" factory built B.E.2Cs during the 1914-18 War but closed its' doors shortly after the war. For a considerable spell, Luton's only connections with Aviation were confined to certain component suppliers.

In the early 1930's, Luton Corporation opened an airfield and in the best traditions of early aviation, this was situated between the local sewage beds and the rubbish tip. In early 1937, the Hunting Aircraft Co. Ltd., then Percival Aircraft Company, moved into Luton and 1940 saw Napier Flight Test Unit arrive, and with the assistance of an E.F.T.S. on the airfield, Luton became aware of the Aircraft Industry. Much later, a branch of the English Electric Co. Ltd. came along, and together with the Aviation Division of Sir Robert MacAlpine, Helicopter Services and the Luton Flying Club (with Hunting Aircraft and Napier), form the principal supporters of Bedfordshire Aviation.

In 1942, largely due to the activities of local Napierians, the Luton Branch came into being and since that time has maintained a fairly steady and peaceful existence. Of the original founder members, the first President Mr. C. Cowdrey, the Manager of the Luton Napier Establishment, Mr. Frank Lester, his P.A., Mr. H. T. Rushton, the Luton Airport Manager and Mr. E. N. Bentley, Chief Airworthiness Engineer at Hunting's are still active members of the Branch. Presidents provide a long list of local celebrities starting with Mr. Cowdrey, then the late Capt. P. D. Acland, Mr. P. Ll. Hunting, the late Mr. D. Vickers, Mr. K. Greenly, Sir Conrad Collier, Mr. W. A. Summers, Mr. A. T. Slator and the President for 1960-61, Mr. F. H. Pollicutt. Mr. Pollicutt, of Hunting Aircraft, was previously with the Bristol Aeroplane Company, and the changing pattern of the Aircraft Industry now puts Hunting in direct touch with Bristol Aircraft through the British Aircraft Corporation. Like the initials "RAF," those of "BAC" mean different things at different periods of aviation history.

This is perhaps a digression, but as with the historical, so Luton also has its geographical and family connections.

Meeting places have ranged from the Luton Girls High School, through various licensed premises to the magnificent hall of the new Luton College of Technology, but the more permanent home is in the Napier Senior Staff Canteen at Luton Airport.

The Branch, as yet, has no Memorial Lecture, but looking at the lecture programmes over the years, most of the big names in the aviation world have appeared on their stage. Certainly one of the most amusing sessions was a debate with the motion:—"Designers and Projects Engineers should throw away their Crystal Balls and read the "Eagle" in lieu." The motion was proposed by the creator of "Dan Dare." As this page is being written on the same day as the first Man in Space is announced, the debate may perhaps be looked back upon as a more serious prophecy than was perhaps thought at the time. The Branch states that their most successful visit was to an Aircraft Carrier and the best attended to the local brewery!

Incidentally, regarding the siting of the airfield, the rubbish tip is still there, but the sewage beds have departed hence and £12,000,000 worth of Vauxhall Motors' factory now occupies the site.

If not of aviation, the motor industry has many links and is a closely allied industry. With the aircraft activities already noted Luton has a wider variety of interest than is found in many a larger Branch.

The present membership is 178, of whom some 65 are Main Society members.

Branch News

Bristol

The Eighth Barnwell Memorial Lecture was given to members of the Bristol branch on 1st March, by Mr. L. G. Frise, one time Chief Designer of the Bristol Aeroplane Company.

His subject was "Some Aspects of Short Haul Freighting." Mr. Frise, who is known to many at Filton, worked with Captain Barnwell and was with the Company from 1916-1946.

After the lecture in the Main Lecture Theatre of the University, some 40 guests were entertained to dinner at the Grand Hotel by B.A.L. Those attending the dinner included Professor Collar, Branch President; Mr. H. Giddings, Chairman; Dr. E. S. Moult, President of the Main society; Mr. C. F. Uwins, Mr. J. F. Harper, Dr. W. Strang and Mr. R. Hafner.

The Annual Meeting of the Branch was held in the Conference Room at Filton House on 8th March, when the main business was the election of branch officers. The retiring President, Prof. A. R. Collar and the Chairman Mr. H. Giddings had served for two years.

The newly-elected President is Mr. R. Hafner, well known to all at Bristol and Chairman is Mr. D. J. Farrar, Chief Engineer, Guided Weapons.

Brough

Having already mentioned the close connection between aviation and the automobile, it is interesting to note the Branch has found an intimate link between the sea and the road (and having no connection with the Hovercraft).

In 1958 two brothers, Mr. K. W. and Mr. L. F. Norris, lectured to Brough on the problems of high-speed travel on water, and in particular their own work as co-designers of Donald Campbell's record-breaking jet-propelled hydroplane.

On March 29th, to close the winter lecture programme, the same brothers Norris spoke on "The New Bluebird," the jet-propelled car in which Mr. Campbell hopes to set up a new world land-speed record. It will be recalled that the car was damaged during a trial run in America last year, but a new attempt on the existing record is to be made at a later date.

Genuine Antiques

1. A good home is required for an Avro Avian, with a view to renovation and preservation for posterity. Unfortunately, neither the Nash Collection nor the Shuttleworth Trust can cope.

2. A Spitfire, preferably Mk. XIX (photo-reconnaissance) is required in an airworthy (or could be made so) condition.

If any Branch Member is interested in 1, or can supply information on 2, please advise—G.W.-W.

Graduates' and Students' Section

The Graduate's First Two Years

Following a past survey by the Graduates' and Students' Section of Industry requirements in academic and technical qualifications, some comments on the Graduate's first years in Industry may be of interest. These are written by a Graduate of six years standing and are based on the experience of some of his contemporaries, gained with several Companies.

The Graduate on entering Industry has an important transition to make. From being the final product of an Institution and in many cases the centre of a family, he joins a Department at a very junior level. Often, the members of that Department do not accept him as a fully-fledged member until he proves his worth—which is best done by deeds. His successful transition depends on himself, the group and on the Company. A difficult transition can be marked by many things and the 'plumbing up' of a seat followed by an interesting display of hydrodynamics is not unknown.

The two-year Graduate Apprenticeships seem to have lost favour—judging from comments. Complaints include: (*i*) too much watching, (*ii*) too many Departments visited, and (*iii*) no planning for their duties.

It is felt that no more than three or four Departments should be visited in the two year course. The Trainees should be regarded as 'permanent' in each Department and action taken to eliminate (*i*), (*ii*) and (*iii*) above. Various combinations of Departments could be selected to give an emphasis on a particular specialisation, and to suit the Trainees' (and Companys') requirements. For example, these could be:

(*a*) Assembly/Drawing Office/Tech. Office/Production.
(*b*) Flight Development/Systems/Aerodynamics/Project.

Others can be thought of, with, in each case, the Trainee staying in the last-named Department. The writer has followed a course similar to (*b*) and has found it excellent for a Performance/Project type of position. Vacation experience and discussions with other employees fill any gaps caused by not working in all the Departments.

Some Departments, such as General Design Office, accept Graduates for permanent employment knowing that the variety of Projects offers sufficient training within the Department. Graduates are often assigned to more experienced engineers who are responsible for assisting their development. This is often the best way where frequent contacts occur with other Departments and external firms. The Graduate can sit-in on meetings and gradually take over responsibility—gaining 'independence' over three to five years. He should not work for one engineer for more than a year.

Another system used where projects vary drastically in content is probably also the most flexible. Under this system individuals are assembled at short notice for a project which may take days or weeks, with minor co-ordinating responsibility assigned generally to one of the more experienced members. In the next project the co-ordinator may find the roles reversed due to specialist knowledge—so he acts accordingly! This system is very flexible and develops leadership in easy stages, but care must be taken that the young Graduate is not lost in circulation.

When joining a Department the Graduate Apprentice or Graduate should generally be assigned a manual containing:

(*i*) all specialist information which he will require,
(*ii*) Company and Department Organisation Chart, and
(*iii*) a job description for his own position.

He should see his Department Head or Deputy-Head at least once a year for general development talks and to review progress. The latter can be done without check-listing ability and character in the 'twenty-tiny squares' with which some Companies appear to become involved.

To sum up, the Company and each Department should plan its organisation with an awareness of the nature of its projects and the type of employee. These are never static and good planning will assimilate and develop the new Graduate in the most efficient manner to the mutual benefit of Graduate and Company.—K.W.S.

Man-Powered Flight

On an evening when the newspaper vendors were doing brisk trade with news of the Soviet 'man-in-space' achievement, a large and enthusiastic audience gathered in the Lecture Theatre at 4 Hamilton Place to hear Mr. B. S. Shenstone lecture to the Section on 'Man Powered Flight—Progress to date'.

It would be true to say that by far the largest part of the lecture was given over to a description of two interesting vehicles which were designed, built and flown before the Second World War. The first aircraft was the Haessler-Villinger aeroplane having a high wing, an aspect ratio of 18·8 and an empty weight of 75 lb. It was powered by one cyclist/pilot who drove a two-bladed propeller of about 5 ft. diameter at 600 r.p.m. via pedals and a belt drive. The propeller was mounted on a vertical pylon just forward of the leading-edge of the wing as a pusher configuration. This aircraft was launched by means of a rubber cable system and achieved a large number of flights of comparatively short duration. However, after a number of modifications flights of over a minute were made, covering distances of the order of 2,000 ft. Mr. Shenstone showed a brief film of the Haessler-Villinger aircraft in flight.

The Bossi-Bonomi aircraft made use of a lone pilot/cyclist to drive two wing-mounted propellers—and also to effect rotation of a small wheel in contact with the ground (to assist take-off). It has been claimed that this aircraft took off successfully without assistance and flights up to five-eighths of a mile were accomplished—this in Italy in 1936.

Other more recent projects were discussed by Mr. Shenstone including flapping-wing and rotor arrangements. He was obviously unable to do no more than mention briefly possible designs for the Kremer Competition.

A number of points arose from his appraisal of the present situation with regard to successful unassisted man powered flight. He thought that the span, and aspect ratio, should be higher than those values so far attempted, and that the diameter of the propeller should be as large as possible.

We are grateful to Mr. Shenstone for an up-to-date picture of further progress in the fascinating art of man powered flight.

Paris Aero Show

Although the official closing day for applications for the visit to Paris during the week-end, 2nd June to 4th June, has passed it is possible that as a result of eleventh hour withdrawals a few places may still be available. Those interested in joining the Graduates' and Students' Section Visit should apply *immediately* to Mr. P. Hampton, Staff Mess, Royal Aircraft Establishment, Farnborough, Hants. The cost of the visit is 10 guineas and this includes all charges for transport from Central London to Paris and hotel accommodation, for both nights, with breakfast.

THE LIBRARY

Reviews

SIR GEORGE CAYLEY: THE INVENTOR OF THE AEROPLANE. *By J. Laurence Pritchard. Parrish, London* 1961. 264 *pp. Illustrated. Index.* 42s.

My only regret about this wonderful book is that the author does not project himself enough; for it is as much a monument to Captain Pritchard as to his subject. It can fall to few men to play such a large part in discovering and establishing a great figure of history, and then to cap it by writing the first full-length biography of him ever to appear.

The story of Cayley's reputation is a strange one. Contemporaries like Henson in the 1840's realised Cayley's key position in aeronautics; and personal friends in various fields of activity were able to assess him at similar high levels throughout his long life (1773-1857). But there was no single contemporary who could assess his all-round stature; and when he died, he was buried to the accompaniment of a miserable little obituary notice in *The Times*, an omission amply atoned for in recent years, however.

Except for obscure pockets of remembrance in the second half of the last century, Cayley's name virtually disappeared from view. As he was not a politician, peer, poet, or other performer in the public eye, and as he never wrote a commentary on St. John's gospel, he does not even appear in the Dictionary of National Biography, although the National Portrait Gallery have at last given in and welcomed him.

It was the late J. E. Hodgson who performed the first major job of rehabilitation; and then Captain Pritchard took over. "J.L.P." from the first appreciated the full stature of Cayley in aeronautics, general science and public life; and he also savoured him to the full as a personality.

Captain Pritchard's paper in the Society's Journal for February 1955 was the next milestone in the modern assessment of Cayley, and an eye-opener for many. Everyone concerned then hoped that this account would lead to a full-scale biography. Now, six years later, that hope has been fulfilled. It is a work undertaken from first to last *con amore;* with the author effacing himself, and allowing his subject to appear through a skilful interweaving of narrative and quotations. There is also a valuable group of appendices where some of the vital Cayley texts are set out in full, one of the most interesting appearing here for the first time in print. The illustrations, over fifty of them, are important documents in themselves; and there is a particularly fine and till now unknown photograph of Cayley taken at the age of seventy. There is, thank heaven, a very good index, clearly compiled by the author and not farmed out in the common and dreadful manner we find in so many books today.

Cayley's diverse interests and accomplishments, and the fact that in his long and busy life he would inevitably be forced to drop a subject and then take it up later, faced Captain Pritchard with a difficult choice; whether to arrange his book by the subjects Cayley pursued, or to tell the story as Cayley lived it, with all the stops and starts and the side-lines branching off on the way. The former would have been easier; Captain Pritchard chose the latter, I am sure quite rightly, and mastered it. He follows Cayley's life as it was lived and thought, and it is the handling of this strange stop-and-start career that so often reveals Cayley's greatness, a greatness that has many similarities to Leonardo da Vinci's; incidentally Cayley was also an uncommonly good illustrator.

The book's sub-title—"the Inventor of the Aeroplane"—might seem to need some justification, even to those in aeronautics; but it is completely correct. Cayley not only laid down (and published) the basis of modern aerodynamics, but he introduced the modern aeroplane concept, with fixed wings, fuselage, and tail-unit comprising pilot-operated elevator and rudder, the machine also incorporating lateral and longitudinal stability. He also built the first man-carrying glider of history.

Although aeronautics takes up a large amount of the book, it is one of the author's main achievements that he brings out admirably the all-round personality and attainments of Cayley. Not only was Cayley an impressive head of family and master of his estates, but he had two other major technological inventions to his credit—the caterpillar tractor and the hot-air engine—and carried out investigations in electricity, acoustics, optics, railway engineering, land reclamation, and half-a-dozen other spheres of activity; he also founded the Regent Street Polytechnic. All these aspects of Cayley's life Captain Pritchard knits fascinatingly together, not forgetting Cayley's strange but inspired education, the later domestic scene—Cayley was very happily married—and the occasional bursts of quite charming doggerel verse in which the Baronet indulged.

Cayley, writes Captain Pritchard, was "an experimental physicist in his outlook, an experimental engineer in much of his work, catholic in his reading, and a man of adventurous ideas and wide interests; He was also a great landowner. His very roots were in the land he loved. He was a leading advocate of social reform; an earnest worker in the general cause of education and for the spread of ideas and knowledge; and one of deep human understanding of the everyday problems of the ordinary man. A man whom the spirit deeply moved."

The present writer is willing to face the severe Laurentian music by expressing gratitude and delight that a great man of today has placed history deeply in his debt by helping to rediscover, and firmly establish for all to see, a great man of yesterday.—C. H. GIBBS-SMITH.

INTERNATIONAL DICTIONARY OF APPLIED MATHEMATICS. *Editor-in-Chief W. F. Freiberger. D. van Nostrand. London. 8,000 entries, 1173 pp. Diagrams. £9. 7s. 6d.*

The Van Nostrand dictionaries and encyclopaedias are well known for their comprehensive, sound and authoritative treatment of their subjects and the Dictionary of Applied Mathematics adds another to this fine collection of reference works. Both the terms and methods of application of mathematics to thirty-two fields of science and engineering are defined and explained clearly by specialists and the illustrative line diagrams and graphs are excellent. The subject matter is chiefly subdivided into large numbers of entries but there is an effective cross reference system throughout which enables individual items to be found; accordingly, a complete answer to a search often requires the reading of several entries, which, although inevitable in the adopted treatment, may suit best the majority of users.

The coverage includes in its scope the older and most of the newer branches of science, such as t sor analysis, quantum mechanics from both a relativistic and a non-relativistic point of view, the applications of topology in the definitions of electrical networks and the extensive use of dynamic analogies for solving problems in mechanics and acoustics: empirical relationships are given in many instances. When standardised tables are given—for example, the atmosphere—the authoritative reference and date would be useful, since these inevitably change through the years.

The invasion and application of mathematics in the fields of the physicist, chemist, aeronautical engineer and metallurgist, and the many other fields, will be evident as soon as anyone dips into the volume, and in view of the increasing amount of scientific papers appearing once more in other languages, the four indices at the end of the volume, which give the English equivalents of German, Russian, French and Spanish technical terms, are most welcome.

This is a volume concisely prepared and easily readable with the main headings and references to other articles in black-faced type.—J. L. NAYLER.

F. W. LANCHESTER: THE LIFE OF AN ENGINEER. *P. W. Kingsford. Edward Arnold. London. 1960. 246 pp. Illustrated. 30s.*

Lanchester is a very well known name in the worlds of the motor car and of aeronautics: F. W. and his brothers all come into the former but only F. W. into the latter. He was undoubtedly a pioneer in science and engineering, an inventor and patentee, a strong-willed man though not lacking in humanity and humour, and one who delighted in controversy in order to uphold his own conclusions. All these aspects are brought out in this life which is well illustrated by subject matter from technical papers and discussions, by letters, by quotations from the Press and other sources, and by humorous anecdotes such as that of the abducted policeman.

The first chapters deal adequately with his inheritance, childhood and early life and another on the first full-sized British petrol-driven motor car follows. Features and devices found in the modern motor car, which had their origin in Lanchester practice are discussed and listed. The succeeding chapters are on mechanical flight and at war. A studied account of the origin and failure of Lanchester's Laboratories Ltd. is given and the book concludes with what was largely frustration in the last few years of Lanchester's life.

This book contains so much of interest about this remarkable personality that its reading was pleasurable. It is, however, very distracting when reading about one subject such as a motor car development to find interjections relating to his aeronautical work of the same period, and vice versa. Readers of the Society's JOURNAL will be more interested in the aeronautical developments where Lanchester's outstanding work on stability, on vortex theory and on aircraft warfare are described in some detail. These details are hard to refind in a book with but a chapter list and no index. Moreover, a specialist in this field could have avoided so many small errors of dates, of facts, of the spelling of scientists' names, of confusion between president and chairman, and to quote merely one example, the actual measured performance by the N.P.L. of the Lanchester aerofoil from R. & M. 109. This laboratory had only a few Cambridge-trained men and the difficulty of understanding Lanchester's early work was general, there and elsewhere, whereas other scientists—sometimes earlier—wrote comprehensible papers on the same subjects. It is true that the N.P.L. neglected the Lanchester-Prandtl theory and the clue is given in a Society's discussion in 1922 which the author reports as follows—"expressed by Bairstow of the N.P.L. that the theory was not sufficiently established to justify the abandonment of the older aerofoil theory."

Justice is done to Lanchester's N-square law in his remarkably far-sighted book *Aircraft in Warfare*. Equally, Lanchester's invaluable work in committee is correctly summarised by the author in the following words: "He would often produce ideas in committee which others would adopt, work on, and gain credit for. These were wrongs which history was to put right, but they were considerable irritants at the time." History put much of this right in Lanchester's lifetime and this is backed by the bibliographies of his writings and published papers to be found in this volume. Sir Harry Ricardo's fine tribute from the Royal Society's Memoir makes a fitting conclusion.—J. L. NAYLER.

NUCLEAR PROPULSION. *M. W. Thring (Editor). Butterworth. London. 1960. 300 pp. 50s.*

A simple analysis of the contents of this book reveals approximately 28 per cent devoted to Nuclear Propulsion, the remainder being divided equally between nuclear matters with no direct bearing on propulsion, and general technical topics also having little relevance to propulsion.

A preface to explain the fact that the book results from a collection of papers presented at a Symposium on Nuclear Propulsion at Sheffield University would help the reader to understand the great variety of subject and style.

It would seem that, the title having been selected, as many subjects as possible were used as the basis for a chapter, however remote the connection with nuclear propulsion. For example, "The Preparation, Storage and Properties of Liquid Hydrogen," going into considerable detail on liquefaction cycles is not very relevant to nuclear propulsion, whereas the use of liquid hydrogen as a nuclear rocket propellant is relevant but gets only a list of advantages and disadvantages which apply to any use of the fluid in a rocket such as "good heat transfer properties, embrittlement of materials and icing-up of valves."

As another example, in a chapter entitled "Medical and Biological Aspects of Life in Sealed Cabins" we learn that in selecting emergency rations—"Palatability should be given some thought" and it would appear that "the minimum emergency ration per man per day is 500 gms. of water and 100 gms. of boiled sweets."

One could choose a number of quotations such as these to illustrate the attempt to cover all aspects of the problems arising from nuclear propulsion. Perhaps the worst example of simply adding the word "nuclear" to justify the inclusion of a chapter is the one by the editor himself entitled "The Thermodynamics of Jet and Rocket Propulsion—The Application of Nuclear Power," which has only two references to nuclear power. One is a footnote to the "combustion heating equation $(A+F)\,c_b\,(T_3-T_2)=f\,.\,Q_b\,.\,\eta_b$" which says that "the equations are identical for nuclear heating if one writes $f=0$ but $Q_b\,.\,f$=heat supplied per second".

Presumably F and f are the fuel flow rate but not both zero at the same time!

The other is a sub-section heading in the treatment of the simple rocket system where we have again "Combustion or Nuclear Heating of the Propellant Fluid".

It would seem possible to work the word Nuclear into almost any discipline—there could have been a chapter on "Nuclear Aerodynamics" or "Nuclear Theory of Structures."

What in the book can be commended? Chapters which fall within the 28 per cent are generally good; mention may be made of those by D. G. Ainley, E. Norton, S. G. Bauer and J. E. R. Holmes, which all deal directly with the subject.

The two years which have passed since the original presentation of the papers have seen many developments. If the book were written now we could expect a much higher proportion of material on nuclear propulsion.

The book would not be a good investment for a student. To show the state of knowledge in 1958 it has some historic value, but will never be a classic.—R. A. SAUNDERS.

SERVOMECHANISMS. *P. L. Taylor. Longmans, London. 1960. 418 pp. Diagrams. 42s.*

This addition to the relatively few British works on servomechanisms belongs to Longman's Electrical Engineering series. A certain bias towards electrical servo is accordingly only to be expected. It is not however allowed to become an obsession; the other common forms of servomechanisms are given adequate treatment, and the use of electrical analogies of non-electrical systems is commendably restrained.

The book, which is of an introductory nature, is aimed at the final year of National Certificate, Diploma of Technology and Degree Courses. It is divided into three parts.

Part I introduces the basic concepts of error-operated devices, the causes and cures of instability, steady-state errors, and the fundamental first- and second-order differential equations of the subject. A chapter on data transmission discusses some of the hardware used in servo systems, both d.c. and a.c. The third chapter in this part is concerned with data computation. It includes sections on the digital computer, analogue computer and associated devices for performing mathematical operations.

Part II develops, mathematically and quantitatively, the ideas introduced in the first part, and includes chapters on stability and performance, amplifiers of various types, rectifiers, motors and hydraulic systems. The subject of non-linearity is given a short chapter to itself. It is confined to an elementary treatment of the effects of saturation, Coulomb friction and backlash. More than this could hardly be expected within the limits which the author has set himself.

The second part concludes with a very well-written

chapter on setting up the systems equations. It is refreshing here to see emphasis laid on the necessity for proceeding in a logical and orderly manner if blunders are to be avoided. An example of an actual position-control servomechanism is introduced for subsequent analysis.

Part III is concerned mainly with the mathematics of servomechanisms. Many authors deal with this aspect rather superficially—some almost apologetically—but Mr. Taylor has not hesitated to give the subject its due weight; this part occupies well over one-third of the book. He builds up the usual stock-in-trade of the servomechanism analyst—Laplace transformation (non-*s*-multiplied, of course), transient and harmonic response, root locus, Nyquist criterion, Bode plots—in a way which brings out clearly the relation of these matters to the basic theory of functions of a complex variable.

The book concludes with a collection of problems, and a bibliography of eighty-odd references.—S. J. GARVEY.

THE PRINCIPLES AND CONSTRUCTION OF AIRCRAFT GAS TURBINES. *R. A. Fry. Pitman, London. 1960. 356 pp. Illustrated. 50s.*

The book is a good explanatory and descriptive text primarily intended for maintenance staff, but it will also be of interest to works supervisors and new entrants to the industry. It is based on the author's experience in training aviation mechanics and engineers.

The aircraft gas turbine is now served by large numbers of people, the majority of whom have no chance to see the subject as a whole. For such, the book can supplement daily experience by satisfying curiosities about working principles, sketching the very advanced technologies of manufacture and construction and providing a wealth of illustrations of components and systems to supplement manufacturer's service manuals.

The book does not deal in any useful detail with such subjects as inspection and testing methods, tooling and crack detection, so it is in no sense a *manual* for maintenance staff. The author mentions his intention to write a further volume on maintenance and overhaul.

The first two chapters, about one-fifth of the book, introduce propulsion systems and elementary turbine theory. Materials, manufacture, mechanical arrangements and construction occupy a further quarter. The remaining chapters deal with reduction gears and propellers, lubrication and oil systems, combustion, fuel and starting systems, and thrust augmentation and reversal. The treatment is not encyclopaedic but it covers much ground in an interesting way.

The book is not intended for the designer but is not likely to offend him. It is strongest on clear descriptions of mechanical parts and weakest on such subjects as combustion design, where the designer finds difficulty. There are over 170 illustrations including many "cut-away" views of engines and components. Diagrammatic layouts of fuel systems, starting arrangements and so on are also a valuable feature.

Apart from a small amount of material under historical notes, the information given is up-to-date and no gross errors were detected.—R. G. VOYSEY.

JANE'S ALL THE WORLD'S AIRCRAFT. *John W. R. Taylor, (Editor). Sampson Low, Marston and Co. London. 1960. £5. 5s. 0d.*

"The Mixture" as before—only, this time, the dispenser is new. John Taylor who became assistant compiler of "Janes" several years ago has now succeeded to the compiler's chair and, quite properly, acknowledges his distinguished predecessors, Fred T. Jane, C. G. Grey and Leonard Bridgman. Despite ominous prognostications by the experts concerning the future of the aircraft industries of the World, the number of new aircraft is higher than before, giving ten extra pages in this section. Guided weapons and pilotless aircraft share 61 pages, an increase of 20 per cent. Special mention should be made of the nuclear power plant and the North American B-70 Mach 3 bomber—notable additions to the book. Photographs of numerous and tiny American single-seater sporting aeroplanes are included accompanied by rather self-conscious crew-cut constructor-pilots. They are included because, having flown successfully, they have a rightful place among the world's aircraft.

The drawings are of a very mixed standard. Some are so crude as to be unworthy of the book at all. The DC-8 is a bad example and the DH-121 Trident drawing has no name printed below it, only the number. But it is so easy to pick little holes in such a vast work. The whole thing is a magnificent reference book. The trends it shows are interesting in many ways, for instance the extraordinary number of conversions of American wartime medium bombers into executive transports and the interesting idea of building First World War fighter types for sporting purposes. The idea of a three-quarter scale Fokker Triplane is intriguing. This together with the Kellett autogyro, basically a design of the early '30's and the Convair Hustler Bomber capable of Mach 2+ gives an indication of the astonishing scope of present day aircraft construction. The time may be coming when the wheel turns full circle and aeroplanes are once again hand-built, one-off affairs as they were 50 years ago, only this time of course they will be so expensive that only a consortium of states could afford to buy one.—A. S. C. L.

Additions to the Library

Applied Thermodynamics. S. H. Bransom. Van Nostrand, London. 1961. 230 pp. Diagrams. Cloth 30s. Students' paperback 22s. 6d. *To be reviewed.*

Calculus of Finite Differences, The. George Boole (edited by J. F. Moulton). 4th Edition. Chelsea Publishing Company, New York. 1960. 336 pp. 1.39 dollars. A classic which first appeared in 1860. This is a paperback reprint of the fourth edition, which presumably appeared some time before 1900. The production of such cheap reprints of classics is a valuable service but one could wish that publishers would list the dates of previous editions.

Sir George Cayley: The Inventor of the Aeroplane. J. Laurence Pritchard. Max Parrish, London. 1961. 264 pp. 42s. *Reviewed in this issue.*

Die deutschen Flugzeuge 1933-45. Karlheinz Kens and Heinz J. Nowarra. Lehmann, Munich. 1961. 816 pp. Illustrated. DM68. *To be reviewed.*

Fate is the Hunter. Ernest K. Gann. Hodder and Stoughton, London. 1961. 352 pp. 21s. *To be reviewed.*

Field Computation in Engineering and Physics. A. Thom and C. J. Apelt. Van Nostrand, London. 1961. 162 pp. Diagrams. 30s. *To be reviewed.*

A History of the Theory of Elasticity and of Trends of Materials. I. Todhunter and K. Pearson. (in 3 volumes). Dover (Constable), London. 1960. 930, 760, 540 pp. 100s. a set. *To be reviewed.*

Plasma Acceleration. Edited by Sidney W. Kash. Stanford University Press, Stanford, California. 1960. 117 pp. Illustrated. 34s. This fourth volume to grow out of Lockheed-sponsored symposia contains nine papers presenting recent experimental and theoretical work on magneto-hydrodynamics. The theory and application in this volume supplement and extend the considerations of the first three volumes. However, this volume has a more definite applied theme: the acceleration of plasma for propulsion for interplanetary travel. The papers present recent experimental and theoretical results concerning the principal means of accelerating ionised material for propulsion, including pulsed magnetic plasma accelerators and d.c. electrostatic ion-electron accelerators. Various geometries are considered, as well as electrodeless and crossed-field configurations. Scaling relations for devices employing fully ionised gases are derived. Detailed information is given on the problems involved and the obtainable thrust, specific impulse, and efficiency.

A Pride of Unicorns. John Pudney. Oldbourne, London. 1960. 240 pp. Illustrated. 21s. *To be reviewed.*

Principles of Astronautics. M. Vertregt. Elsevier, Amsterdam (van Nostrand, London). 1961. 221 pp. Diagrams. 18s. *To be reviewed.*

Science and Government. C. P. Snow. Oxford University Press, London. 1961. 88 pp. 9s. 6d. *To be reviewed.*

Starten und Fliegen. Edited by Otto Fuchs *et al.* Deutsche Verlags Anstalt, Stuttgart. 1960. 385 pp. Illustrated. DM 16.80. *To be reviewed.*

Technische Strömungslehre. Bruno Eck. 6th Edition. Springer, Berlin. 1961. 453 pp. Illustrated. DM 31.50. The 4th edition of this book was reviewed in the November, 1954 Journal (p. 792) as "a book that can readily be used by engineers for the solution of practical problems in a field which includes direct application to aircraft" and "a useful contribution to applied fluid mechanics". Earlier editions appeared in 1941, 1944, 1949, 1954 and 1957.

Transport of Invalids by Air, The. K. G. Bergin. B.O.A.C. 1961. 15 pp. Illustrated. No price.

Weight-Strength Analysis of Aircraft Structures. F. R. Shanley. 2nd edition. Dover Publications, New York. 1960. 404 pp. Diagrams. 2.45 dollars. A paper-bound edition of the book reviewed in the June 1953 Journal (p. 423); this review pointed out the value of bringing together in one volume a large amount of work on structural "design"(as opposed to "analysis") and of encouraging the further development of the principles of weight-strength analysis and, in particular, the application of the principles of structural design for minimum weight. The original volume is well known and this cheap edition is welcome.

I.A.S. PAPERS
29th Annual Meeting
New York, 23rd-25th Jan. 1961

61-1 Sandwich construction for primary structure of ballistic missiles and space vehicles. R. F. Foral.

61-2 Design procedures for structures under non-uniform temperature distribution. I. Axial loads and bending moments. B. E. Gatewood and R. W. Gehring.

61-3 Experimental investigation of lithium hydride and water absorbers as possible heat-sink materials for hypersonic and re-entry vehicles. R. O. Hickel *et al.*

61-4 Optimum design of integral fuselage propellant tanks for use in high performance aircraft. I. Rattinger *et al.*

61-5 Change of satellite orbit plane by aerodynamic manoeuvering. H. S. London.

61-6 Determination of the lift or drag program that minimizes re-entry heating with acceleration or range constraints using a steepest descent computation procedure. A. E. Bryson *et al.*

61-7 Variation of parameters for near circular and low inclination orbits. S. Pines.

61-8 Asymptotic expansions of the solutions of the equations of motion in the earth-moon space. A. Zukerman.

61-9 Guidance error analysis of satellite trajectories. H. S. Braham and L. J. Skidmore.

61-10 Preliminary comparison of air and ground launching of satellite rendezvous vehicles. T. N. Edelbaum.

61-11 Analysis of the vertical floating (Hydra) launch of rocket vehicles. J. E. Draim and C. E. Stalzer.

61-12 Corrosion problems encountered in silo storage of missiles. L. E. Gatzek.

61-13 Thermal stresses in the bending of ogival shells. C. N. De Silva.

61-14 Stresses and deformations of the thin-walled pressurized torus. P. F. Jordan.

61-15 General formulas for influence coefficients for thin spherical shells. N. J. Hoff.

61-16 A criterion for dynamic buckling of shallow shells under uniform impulsive loading. J. S. Humphreys and S. R. Bodner.

61-17 On the design of hypersonic aircraft. H. Multhopp.

61-18 Space cooling procedures. M. Macklin.

61-19 General considerations for satellite attitude control systems. J. S. White and J. S. Pappas.

61-20 Liquid behavior in a zero-G field. Ta Li.

61-21 Application of inequality constraints to variational problems of lifting re-entry. E. S. Levensky.

61-22 On the PLK method and the supersonic blunt body problem. R. Vaglio-Laurin.

61-23 Viscous and inviscid non-equilibrium gas flows. R. J. Whalen.

61-24 Elements of solar collector design. D. L. Dresser.

61-25 Variation of rotor dynamic response by self-contained mechanical feedback. G. J. Sissingh.

61-26 Helicopter tire design to control mechanical instability. R. Jones.

61-27 Future performance capabilities of rotary wing VTOL aircraft. P. J. Carpenter.

61-28 An experimental investigation of stall flutter. N. D. Ham.

61-29 An investigation of improved flying qualities for tandem rotor helicopters. J. A. De Tore.

61-30 Bending vibrations of a perforated grain solid propellant rocket during powered flight. S. Birnbaum.

61-31 Unsteady aerodynamic forces on slender supersonic aircraft with flexible wings and bodies. J. E. Yates and E. F. E. Zeijdel.

61-32 The response of linear systems to inhomogeneous random excitation. M. Botman.

61-33 Development of a quasi-steady approach to flutter and correlation of quasi-steady and kernel function flutter analysis. S. I. Gravitz *et al.*

61-34 Propeller—nacelle whirl flutter. J. C. Houbolt and W. H. Reed.

61-35 Trajectory considerations for circumlunar missions. W. H. Michael and J. W. Crenshaw.

61-36 The trajectories and some practical guidance considerations for rendezvous and return. J. M. Eggleston.

61-37 Pilot control of rendezvous. M. C. Kurbjun *et al.*

61-39 New developments in the design of model reference adaptive control systems. P. V. Osburn *et al.*

61-40 The electrical properties of the air around a re-entering body. G. F. Pippert and S. Edelberg.

61-41 The hydrodynamic characteristics of high speed hydrofoils. V. E. Johnson and M. P. Tulin.

61-42 Aircraft techniques applied to submarines. J. D. Malloy.

61-43 Hydrodynamic factors in submarine design and their relationship to aerodynamics. R. K. McCandliss.

61-44 Hydrofoils at the crossroads. J. J. Stilwell *et al.*

61-45 Some design problems of hovercraft. R. S. Jones.

61-46 A conceptual nuclear propulsion system for ground effect machines. J. C. Westmoreland *et al.*

61-47 GEM design philosophy for an over-water, over-ice vehicle. O. Ljungstrom.

61-48 Ground effect machine propulsion system design consideration. L. W. Norman.

61-49 A study of manned nuclear-rocket missions to Mars. S. C. Himmel *et al.*

61-50 Combustion instability in liquid propellant rockets—a review. R. B. Lawhead.

61-51 Launch-vehicle recovery techniques. C. A. Lysdale.

61-52 Propulsion systems for laminar flow aircraft. J. W. Connors *et al.*

61-53 Helicopter instrument certification. H. H. Hermes and C. M. Seibel.

61-54 East Coast FAA helicopter operations. F. Freeman.

61-55 Development of navy helicopter instrumentation. L. S. Guarino.

61-56 Army-Navy Instrumentation Program—Rotary wing phase. N. E. Welter.

61-57 The application of satellites for commercial communication purposes. L. Jaffe.

61-58 Commercial applications of satellite boosters. B. Graham.

61-59 The satellite vehicle for communications. H. M. Wittner and W. J. Roths.

61-60 Study of VTOL control requirements during hovering and low-speed flight under IFR conditions. W. J. Klinar and S. J. Craig.

61-62 A new look at V/STOL flying qualities. R. C. A'harrah and S. F. Kwiatkowski.

61-63 Flight test experience with the XV-3 low-disc-loading V/STOL aircraft. C. E. Davis and R. L. Lichten.

61-64 Nuclear rocket stages increase Saturn's payload capability. W. Y. Jordan. *et al.*

61-65 Kiwi-A: The first rocket reactor experiment. R. E. Schreiber.

61-66 Nuclear electric power for space missions. T. W. Koerner and J. J. Paulson.

61-67 Safety considerations for nuclear power in aerospace. J. A. Connor.

61-68 The Geocorona. H. Friedman.

61-69 Preliminary stability, control and handling criteria for ground effect machines (GEMS). N. K. Walker.

61-70 An approach to the operational features desirable in a military acceptable GEM. P. G. Fielding.

61-71 Basiic prnciples of the stability of peripheral jet ground effect machines. M. C. Eames.

61-72 Experimental research on the cesium thermionic converter. N. S. Rasor.

61-73 Thermionic conversion of heat to electricity. W. B. Nottingham *et al.*

61-74 The RIAS enterprise—a pattern for the expansion of basic research in the aerospace industry. W. W. Bender.

61-75 Feasibility of a T.V. satellite. L. Pollock.

61-76 Economics of instrumentation precision for space vehicle development. V. R. Boulton.

61-77 Navy interest in meteorological satellites. J. F. Tatom.

61-78 Tektites and natural satellites of the earth. J. A. O'Keefe and B. Shute.

61-79 Translational characteristics of ground effect machines. W. W. Royce and S. Rethorst.

61-80 Design selection and performance of a lifting fan V/STOL logistic transport. E. Kazan and W. Bergen.

Reports

NOTE—Most of the reports listed are available on loan to bonafide inquirers, but the Society is not agent for the sale of any of them. The great majority of the reports are "unpublished" and are not, therefore, obtainable through booksellers or other agents. Notable exceptions are the R. & M. and C.P. series which can be bought through Her Majesty's Stationery Office.

AERODYNAMICS

BOUNDARY LAYER *see also* INTERNAL FLOW
PERFORMANCE
HELICOPTER AERODYNAMICS
AIRCRAFT OPERATION

A preliminary note on a modified type of air jet for boundary layer control. R. A. Wallis. C.P. 513. 1960.
An attempt has been made to develop a type of air jet capable of producing persistent vorticity to delay turbulent separation and, in particular, shock induced separation. Experiments with circular jets, suitably pitched and inclined at an angle to the surface in the cross flow direction, show considerable promise.—(1.1.6.1).

The effects of distributed suction on the development of turbulent boundary layers. R. A. Dutton. R. & M. 3155. 1960.
Experiments on the turbulent boundary layer with uniform suction and with zero pressure gradient are described. The test surface consisted of a uniformly perforated sheet which replaced the floor of a wind tunnel, the tunnel boundary layer being removed through a slot a short distance ahead of the test section. For several different suction velocities, and for different entry conditions boundary layer measurements were made on the perforated surface and on a porous surface formed by covering the perforated sheet with calendered nylon fabric.—(1.1.5.1).

Turbulent skin friction at high Mach number and Reynolds numbers in air and helium. F. W. Matting et al. *N.A.S.A. T.R. R*-82. 1960.
Results are given of local skin-friction measurements in turbulent boundary layers over an equivalent air Mach number range from 0·2 to 9·9 and an over-all Reynolds number variation of 2×10^6 to 100×10^6. Direct force measurements were made by means of a floating element. Flows were two-dimensional over a smooth flat surface with essentially zero pressure gradient and with adiabatic conditions at the wall. Air and helium were used as working fluids. An equivalence parameter for comparing boundary layers in different working fluids is derived and the experimental verification of the parameter is demonstrated. Experimental results are compared with results obtained by several methods of calculating skin friction in the turbulent boundary layer.—(1.1.3).

An experimental investigation of boundary-layer control for drag reduction of a swept-wing section at low speed and high Reynolds numbers. D. E. Gault. N.A.S.A. T.N. D-320. *Oct.* 1960.
The model, installed between end plates, was a constant-chord wing panel with 30° of sweepback and a modified N.A.C.A. 66-012 aerofoil section in the streamwise direction. Boundary layer control was applied to only the upper surface of the model through 93 spanwise slots between the 0·0052- and 0·97-chord stations. Tests were made at angles of attack 0°, ±1·0°, ±1·5° and −2·0° for Reynolds numbers from about 11×10^6 to 29×10^6 based on the streamwise chord.—(1.1.5.1).

Shock-wave laminar-boundary-layer interaction on a convex wall. I. Greber. N.A.S.A. T.N. D-512. *Oct.* 1960.
Results of experimental and theoretical studies of the interaction of oblique shock waves with laminar boundary layers on a curved surface are presented. The theoretical work extends a flat-plate model to include the effects of surface curvature on the pressure levels characteristic of separation and on the length of the separated region.—(1.1.1.4).

Mise en oeuvre d'un procédé de détermination expérimentale du domaine transsonique dans un écoulement de type mixte. G. Gontier. Pubs. Sc. et. Tech. 367. 1960. (*In French*).
In a mixed flow (partly subsonic, partly supersonic) the velocity potential is expressed by a polynomial of which the coefficients have been determined from the velocity distribution along a given curve. The velocity field was verified experimentally: the most important result was the evidence (obtained by a "transometric" probe) of a transonic region where the speed was supersonic but where a small perturbation affected the subsonic region upstream. This upstream influence had to be separated from that transmitted through subsonic regions of the boundary layer.—(1.1.2.3×1.5.1.4×1.12.5).

Équations intrinsèques du mouvement a trois dimensions des fluides a viscosité. F-J Bourrières. Pubs. Sc. et Tech. 368. 1960. (*In French.*)
The report extends to three dimensions the intrinsic two-dimensional equations of continuous movement in incompressible viscous fluids. The selection of suitable variables and intrinsic functions is discussed, and a theorem, apparently new and basic, relating the longitudinal geometric properties of the whole three-dimensional field to its transonic properties. The analysis makes use of the conceptions of torsion and of geodisic curvature.—(1.1.1.1×22.2×1.4×17.1).

COMPRESSIBLE FLOW *see also* INTERNAL FLOW
LOADS
WINGS AND AEROFOILS
AIRCRAFT OPERATION
EXTRA-ATMOSPHERIC TECHNOLOGY
MISSILES

Wall interference at transonic speeds on a hemisphere-cylinder model. E. W. E. Rogers and I. M. Hall. C.P. 510. 1960.
Tests have been made in three N.P.L. wind tunnels on a pressure-plotting model consisting of a long cylinder with a hemispherical nose. The surface pressure distributions were measured for stream Mach numbers between 0·7 and 1.1 at zero model incidence, and schlieren photographs were taken. The blockage ratios were 0·211 per cent, 0·117 per cent and 0·120 per cent.—(1.2.2.2×1.12.1.2×1.6.1).

Axial-force reduction by interference between jet and neighboring afterbody. W. C. Pitts and L. E. Wiggins. N.A.S.A. T.N. D-332. *September* 1960.
Experimental results are presented for axial force, normal force and centre of pressure. The test Mach number was 2·94, the jet Mach number 2·71, and the Reynolds number $0\cdot25\times10^6$ based on body diameter. The variables include static-pressure ratio of the jet (up to 9), nacelle position relative to the afterbody, angle of attack (−5° to 10°), and afterbody shape.—(1.2.3×1.8.2).

CONTROLS *see* PERFORMANCE
STABILITY AND CONTROL

FLUID DYNAMICS *see also* BOUNDARY LAYER
INTERNAL FLOW
MATHEMATICS

The steady flow of a viscous fluid past a circular cylinder at Reynolds numbers 40 *and* 44. *C. J. Apelt. R. & M.* 3175. 1961.—(1.4).

INTERNAL FLOW *see also* BOUNDARY LAYER
TESTING AND INSTRUMENTS

Static tests on a conical centrebody supersonic air intake with an auxiliary air inlet slot. M. Cox. C.P. 515. 1960.
A simple method is given of calculating changes in pressure recovery with intake flow rate and bleed slot opening, which should be applicable to other intake and auxiliary inlet configurations.—(1.5).

The design and testing of an axial-flow compressor having different blade profiles in each stage. A. D. S. Carter et al. *R. & M.* 3183. 1960.
A brief survey is given of various blade profiles and their two-dimensional cascade performance characteristics. The requirements of the different stages of an axial compressor are discussed and the design details given of a suitable test compressor embodying in each stage the blade profile most suited to the duty that stage has to perform. Test results for this compressor are discussed.—(1.5.2.1×1.5.4.2).

The effect of Reynolds number on the performance of a single-stage compressor. A. D. S. Carter et al. *R. & M.* 3184. 1960.
The Reynolds number effects on the performance of a single-

stage compressor have been measured over the range $0{\cdot}08\times10^5$ to $9{\cdot}0\times10^5$. The tests were made in a variable-density return-circuit rig and the Reynolds number varied partly by fluid density and partly by speed.—(1.5.2.1).

An experimental study of perforated intake diffusers at a Mach number of 2.50. *J. H. T. Wu. U.T.I.A. Report* 69. *September* 1960.—(1.5.1×1.2.3).

Design and calibration of an air ejector to operate against various back pressures. R. G. A. Chisholm. U.T.I.A. T.N. 39. *Sept.* 1960.
As part of a wind tunnel investigation an air ejector was designed and built to act as a "step-down transformer" between a high pressure air supply and the models. It consisted of a central primary jet discharging into a constant area mixing tube. The thrust and mass augmentation of this ejector were determined for various mixing-tube back pressures. These experiments were for a convergent primary nozzle and a supersonic one, and for two diameters of the mixing tube with the latter nozzle. The effects of the primary mass flow on the mass and thrust augmentation were obtained for the sonic primary. A comparison between the experimental results and those predicted by a theory developed in this paper was made.—(1.5).

Studies of ground effect on an inwardly inclined annular jet. Part I. Apparatus and method of testing; effects of aspect ratio and pressure ratio. D. B. Garland. U.T.I.A. T.N. 37. *Aug.* 1960.
A series of tests was made with a 60° inwardly inclined annular nozzle over a wide range of nozzle aspect ratios ($67\leqslant AR\leqslant524$), pressure ratios (up to 3·0), with and without the presence of simulated ground. Total thrust force was measured and converted to augmentation ratio, using the ideal thrust of an equivalent circular nozzle in free-air as a basis. Nozzle angle of attack was held at zero degrees. Base pressure distributions and nozzle mass flows were also measured and will be published later in Part II.—(1.5×5.12×5.13).

Contribution a l'étude du rendement d'une turbomachine axiale a fluide incompressible. R. Comolet. Pubs. Sc. et Tech. 372. 1960.
The usual methods of analysis of the flow of incompressible fluids through axial flow compressors and turbines do not always give the energy losses in the fixed stages, but it is possible to give an exact expression for the analysis of a complete stage. The importance of losses in the stator are thus shown up particularly clearly. Conditions for improved running are discussed and a definition of optimum value is given for the ratio external diameter of rotor : diameter of disc.—(1.5.2.1×1.5.3.1)

Étude de l'écoulement d' un fluide dans un tunnel prismatique de section trapezoidale. E. Rodet. Pubs. Sc. et. Tech. 369. 1960.
Turbulent flow is studied in a prismatic tunnel of trapezoidal section and mean velocities at the centre of the flow were measured by Pitot tube. A hot wire anemometer was used to measure mean velocities in the laminar sublayer and Reynolds stresses in the whole section. Evidence is given that maximum velocity and minimum turbulence occur in the angles of the section. The distribution of friction at the wall was investigated. The distributions of velocity and friction at the wall in the laminar region were examined by a relaxation method with a view to comparing it with the turbulent region.—(1.5.1.4×1.12.1.1×1.1.1.1×1.1.2.1×1.4.2).

Sur le calcul des grilles de profils. A. Papon. Pubs. Sc. et Tech. B.S.T. 125. 1960. (*In French.*)
Different methods of constructing cascades to fulfil certain geometrical and aerodynamic conditions are studied and solutions of various authors are examined and commented on. A solution by means of a conformal transformation is given for the case when entry and exit angles of the air, and non-dimensional pitch of the cascade is known. Examples are given and experimental and theoretical results compared.—(1.5.4.1).

LOADS *see also* COMPRESSIBLE FLOW
STABILITY AND CONTROL
WINGS AND AEROFOILS

Atmospheric turbulence encountered by a Fairchild C-119 aircraft over the Canadian Arctic. R. T. Sewell. N.R.C. Report L.R.-290. Nov. 1960.
From the limited number of records obtained, it would appear that the frequency of occurrence of vertical gusts exceeding 10 ft./sec. equivalent velocity is considerably lower than that suggested by R.Ae.S. Fatigue Data Sheet L01.01 as representing a world-wide average. It is considered that the analysis does not represent a true statistical average, and the results might be considerably modified if records were to be obtained over a longer period.—(1.6.3×31.3.1×3.6).

The application of a Lighthill formula for numerical calculation of pressure distributions on bodies of revolution at supersonic speed and zero angle of attack. L. Ohman. S.A.A.B. T.N. 45. 1960.
An integral expression, given by Lighthill and based on linearised theory, for the external supersonic flow over the surface of slender pointed or ducted bodies of revolution at zero angle of attack is shown to give a good approximation of the exact flow for a wider Mach number and thickness range than could be expected from linearised theory. A numerical method, based on this expression, is developed and applied for digital computing. Results from applying the digital computing procedure for determining the pressure distribution and wave drag for various bodies of revolution are given.—(1.6.1×1.2.3.1).

PERFORMANCE. *See also* FLIGHT TESTING.

Large-scale wind-tunnel tests and evaluation of the low-speed performance of a 35° *sweptback wing jet transport model equipped with a blowing boundary-layer-control flap and leading-edge slot. D. H. Hickey and K. Aoyagi. N.A.S.A. T.N. D-*333. *Oct.* 1960.
The typical four-engine jet transport model had a wing of aspect ratio 7. Three-component longitudinal force and moment data and boundary layer flow requirements are presented and the test results are analysed in terms of estimated take-off and landing performance. The effect on performance of the source of boundary layer control air flow is considered.—(1.7.1×1.1.6.1×1.3.4×1.3.7×1.8.2.2).

*An investigation of landing-contact conditions for a large turbojet transport during routine daylight operations. J. W. Stickle and N. S. Silsby. N.A.S.A. T.N. D-*527. *Oct.* 1960.
Statistics are presented of the landing-contact conditions of vertical velocity, airspeed, rolling velocity, bank angle, and distance from the runway threshold for 103 landings of a large turbojet transport during routine daytime operations at the Los Angeles International Airport.—(1.7.1×13.1×5.1).

*Measurement of the maximum altitude attained by the X-*15 *airplane powered with interim rocket engines. W. H. Stillwell and T. J. Larson. N.A.S.A. D-*623. *Oct.* 1960.—(1.7×3.6×13.3×1.12.2).

STABILITY AND CONTROL *see also* COMPRESSIBLE FLOW
PERFORMANCE
WINGS AND AEROFOILS
AIRCRAFT
EXTRA-ATMOSPHERIC TECHNOLOGY
FLIGHT TESTING

A semi-empirical method for estimating the rotary rolling moment derivatives of swept and slender wings. W. J. G. Pinsker. C.P. 524. 1960.
A method is derived for estimating the derivatives l_p and l_r of swept and delta wings based on theoretical data and steady six component wind tunnel results. Good agreement is obtained with values of l_p measured on a rolling balance for a series of narrow delta wings.—(1.8.1.2).

A new standard for the prediction of full-scale spin and recovery characteristics from model tests. T. H. Kerr. R. & M. 3130. 1960.
The important features of a model, which affect the scale effect in the spin and recovery are discussed in the light of several model to full-scale comparisons and the general background of spinning experience. These features have been shown to be the λ of the spin, the thickness/chord ratio of the wing and the inertia ratio B/A of the model. Using these parameters, a new standard for the prediction of the full-scale spin and recovery from the model test is presented.—(1.8.3.1).

Explanation of poorly damped lateral oscillations during automatic approach with aileron steering. K. H. Doetsch. R. & M. 3159. 1960.

Poorly damped Dutch-roll oscillations were experienced during landing approaches on different aircraft when controlled by an auto-pilot employing the aileron-steering technique. This phenomenon is explained with the aid of the time-vector representation and remedies are discussed.—(1.8.2.1×13.2).

Summary and analysis of horizontal-tail contribution to longitudinal stability of swept-wing airplanes at low speeds. R. H. Neely and R. F. Griner. N.A.S.A. T.R. R-49. 1959.
Air flow characteristics behind wings and wing-body combinations are described and are related to the downwash at specific tail locations for unseparated and separated flow conditions. The effects of various parameters and control devices on the air flow characteristics and tail contribution are analysed and demonstrated. An attempt is made to summarise certain data in a form useful for design. The experimental data were obtained mostly at Reynolds numbers greater than 4×10^6 and at Mach numbers less than 0·25.—(1.8.2.2×1.6.1×1.10.2.2).

Aileron control of small-aspect-ratio aircraft; in particular, delta aircaft. W. J. G. Pinsker. R. & M. 3188. 1960.
The aerodynamic and inertia characteristics associated with small aspect ratio wings are shown to affect aileron control, causing a tendency towards excessive aileron power combined with poor initial response. Simple formulae are given for the determination of the critical parameters and the effects of these on some aileron manoeuvres are analysed. Touchiness of lateral trimming is also expected to add to the handling difficulties of such aircraft. Design criteria are discussed for the attainment of optimum aileron control.—(1.8.1.1×1.3.1.1).

THERMO-AERODYNAMICS

A visual technique for determining qualitative aerodynamic heating rates on complex configurations. P. C. Stainback. N.A.S.A. T.N. D-385. Oct. 1960.—(1.9.1×1.12.1).

Beitrag zur Thermodynamik der Überschallstromung. O. Lutz et al. *D.F.L. Bericht* 123. 1960.—(1.9.3).

WINGS AND AEROFOILS *see also* STABILITY AND CONTROL

The shapes and lift-dependent drags of some sweptback wings designed for $M_0=1{\cdot}2$. J. A. Bagley and J. A. Beasley. C.P. 512. 1960.—(1.10.1.2×1.2.2.1).

Wind tunnel measurements of lift, drag and pitching moment of two highly swept ($\Lambda_{LE}=87$ deg. and 81 deg.) delta wing-body combination models with small tip fins at $M=2{\cdot}47$. P. J. Bateman. C.P. 514. 1960.
Tests have been made to explore the aerodynamic possibility of a feasible aircraft design based on a highly swept (over 80°) delta planform with sufficient body depth in the region of the centre of gravity to accommodate the lifting jet engines required for take-off and landing. Two models were tested, of 87° and 81° leading edge sweepback respectively.—(1.10.2.2×1.8.2.2).

Wind tunnel measurements of the lift-drag of thin conically cambered slender delta wings at Mach numbers 1·4 and 1·8. M. S. Igglesden. C.P. 519. 1960.
Lift and drag have been measured, at Mach number 1·4 and 1.8, on two sets of thin slender delta wings (aspect ratio 4/3) with differing degrees of conical leading edge camber, one set having drooped edges, and the other having edges shaped to give parabolic upwash distributions over the cambered part. An uncambered wing was included. All had sharp leading edges. Information on the effective leading-edge suction, the nature of non-linearities in lift curve slope and the influence of free and fixed boundary layer transition on the chord force is discussed.—(1.10.2.2).

Some notes on the flow patterns observed over various swept-back wings at low Mach numbers in the R.A.E. 10-ft.×7-ft. high speed tunnel. A. B. Haines. R. & M. 3192. 1960.
The flow patterns observed by an oil film (titanium oxide) over ten different swept-back wings at high incidence and low Mach number in the R.A.E. 10 ft. × 7 ft. High Speed Tunnel are collated. The designs range from 0·04 to 0·10 in. mean thickness/chord ratio and from 40° to 60° in angle of sweep. How the regions of flow separation, together with their associated part-span vortex sheets are affected by change in incidence, Reynolds number and wing design are discussed. Brief reference is made to how the flow patterns are related to the overall force and moment characteristics and how those characteristics might be improved by different types of modification.—(1.10.2.2).

Transonic and supersonic wind-tunnel tests of wing-body combinations designed for high efficiency at a Mach number of 1·41. F. C. Grant and J. R. Sevier. N.A.S.A. T.N. D-435. Oct. 1960.
Results are shown for four differently indented bodies in combination with two differently warped wings. For comparison, data for an aeroplane wing and two non-indented bodies are also shown. All wings had the same highly swept discontinuously tapered planform with N.A.C.A. 65A-series aerofoil sections 4 per cent thick at the root tapering to 3 per cent thick at the tip.—(1.10.2.2×1.8.2.2×1.2.3).

Basic pressure measurements at a Mach number of 1·43 on a thin 45° sweptback highy tapered wing with systematic spanwise twist variations. J. P. Mugler and E. R. Woodall. N.A.S.A. T.N. D-528. Oct. 1960.
Pressure data are presented on an untwisted wing, and wings with linear, quadratic, and cubic twist variations. The tests were made at a Mach number of 1·43 and covered an angle of attack range from −4° to 20°. The average Reynolds number based on the wing mean aerodynamic chord was $2{\cdot}9\times10^6$ during tests at 1·0 atmosphere and $1{\cdot}5\times10^6$ during tests at 0·5 atmosphere.—(1.10.2.2×1.6.1).

Characteristics at Mach number of 2·03 of a series of wings having various spanwise distributions of thickness ratio and chord. A. W. Robins et al. *N.A.S.A. T.N. D-631. Oct.* 1960.
A series of semi-span wing models having the same effective thickness ratio was tested in the Langley 4×4 ft. supersonic pressure tunnel at Reynolds numbers from $1{\cdot}9\times10^6$ to $6{\cdot}5\times10^6$ based on mean geometric chord. A calculative technique for the determination of zero-lift wave drag has been applied to one of the complex wings of the series and good agreement is shown with experimental results.—(1.10.2.2×1.8.2.2).

Chronophotographie électronique application a l'étude de phénomènes aérodynamiques évolutifs. G. Bataille. Pubs. Sc. et Tech. 371. 1960. (*In French.*)
A method of flow visualisation for non-steady flows is discussed. Quantitative results show the similarity conditions which govern the study of short wakes; the forces on moving bodies can be deduced from the experimental data of the speed of establishment of the velocity field around the body.—(1.10.2.1×1.12.6).

An experimental and theoretical investigation of second-order supersonic wing-body interference, for a non-lifting body with wings at incidence. P. G. Wilby. F.F.A. Report 87. 1960.
Pressure distributions on the wing of two wing-body combinations are measured experimentally at Mach numbers 3 and 4 with the wing at various incidences in the range 0° to 10°. The results are compared with theoretical results which include interference effects calculated according to the second-order supersonic wing-body interference theory due to Landhal and Beane. This theory, having been tested previously for non-lifting wing-body combinations, is thus tested also for wings at incidence.—(1.10.0.2×1.2.3.1).

HELICOPTER AERODYNAMICS

An analysis of the lateral-directional stability and control of the single-rotor helicopter. G. F. Langdon and M. C. Neale. R. & M. 3149. 1960.—(1.11.2).

Full-scale wind-tunnel tests of blowing boundary-layer control applied to a helicopter rotor. J. L. McCloud et al. *N.A.S.A. T.N. D-335. Dec.* 1960.—(1.11.3×1.1.6.1).

TESTING AND INSTRUMENTS *see also* BOUNDARY LAYER
COMPRESSIBLE FLOW
INTERNAL FLOW
PERFORMANCE
THERMO-AERODYNAMICS
WINGS AND AEROFOILS
FLIGHT TESTING

Development of capacitance and inductance driven hotshot tunnels. J. Lukasiewicz et al. *A.E.D.C.-T.N.-60-222.* 1961.
Results of measurements made over the past year in the arc chambers and test sections of the hotshot-type wind tunnels of the U.S.A.F.-A.R.D.C. Arnold Engineering Development Center and of the Boeing Airplane Company are presented for operation with air and nitrogen at stagnation temperatures up to 4000°K and maximum reservoir pressures up to 40,000

lb./in.². Data on contamination of the flow with arc-chamber components, throat erosion, flow distribution on the test section, effects on heat transfer and force measurements are discussed. —(1.12.1.3).

The performance and operation of the University of Southampton hypersonic gun tunnel. R. A. East. U.S.A.A. Report 135. *August* 1960.
Theoretical and experimental investigations into the performance and operation of the University of Southampton Hypersonic Gun Tunnel are described. The assumptions on which performance estimates have been based, have been critically examined in the light of experimental results. The results of the first 500 runs designed to study the mechanism of operation, and to determine reservoir and test section conditions are described, and a preliminary calibration of the 2 in. diameter conical nozzle given. The effect of heat loss from the reservoir has been considered. Conclusions are drawn from the experiments on the limitations on operational performance and the usefulness of the hypersonic gun in hypersonic research and its possible development are considered.—(1.12.1.3 × 1.5.1.4).

El Problema de la Estabilización de la Soplante del Túnel Subsónico Grande del I.Ae. O. A. Lindemann. Comunicaciones e Informes 13. *Argentina.* (*In Spanish.*)—(1.12.1.1).

AEROELASTICITY

See also MATHEMATICS

Wind tunnel flutter tests on an M-planform wing. W. G. Molyneux. C.P. 509. 1960.
Tests were made in a low speed open jet wind tunnel to obtain the effects on the flutter of an *M*-wing of variation of inertia parameters of a nacelle at the wing kink. The effect of fuselage mobility was also investigated.—(2).

AIRCRAFT

See also AERODYNAMICS—LOADS
PERFORMANCE
EXTRA-ATMOSPHERIC TECHNOLOGY
FLIGHT TESTING

Large-scale wind-tunnel tests of a wingless vertical take-off and landing aircraft—preliminary results. D. G. Koenig and J. A. Brady. N.A.S.A. T.N. D-326. *Oct.* 1960.—(3.12 × 1.8.0.2 × 29.7).

AIRCRAFT OPERATION

See also AERODYNAMICS—INTERNAL FLOW
PERFORMANCE

Flight measurement of wall-pressure fluctuations and boundary-layer turbulence. H. R. Mull and J. S. Algranti. N.A.S.A. T.N. D-280. *Oct.* 1960.
Boundary layer velocity profiles, wall-pressure fluctuations, turbulence intensity, and associated spectral distributions for pressure altitudes of 10,000, 20,000, and 30,000 ft. and for subsonic Mach numbers in the range 0·3 to 0·8 were measured at forward fuselage and wing stations on a jet fighter.—(5.6 × 1.1.3.2).

A summary of operating conditions experienced by three military helicopters and a mountain-based commercial helicopter. A. B. Connor. N.A.S.A. T.N. D-432. *Oct.* 1960.
Flight conditions comprising the flight profiles of three military helicopters engaged in simulated and actual military missions, and of a commercial helicopter engaged in mountainous, high-altitude missions are presented. Tables and graphs present the results that were obtained by N.A.S.A. helicopter V.G.H.N. recorders.—(5.4).

Distribution of time-averaged pressure fluctuations along the boundary of a round subsonic jet. W. L. Howes. N.A.S.A. T.N. D-468. *Oct.* 1960.
A semi-empirical analysis is used to predict the shape of the time-averaged fluctuation-pressure distribution.—(5.6 × 27.1 × 1.2.1.1).

Einführung in die Unternehmensforschung (*Operations Research*). *W. Schultz. D.F.L. Bericht* 127. 1960. (*In German.*)—(5.1.1. × 28).

Ein Beitrag zur rechnerischen Behandlung des Entfaltungsstosses von Fallschirmen. W. Heins und R. Ludwig. D.F.L. Bericht 128. 1960. (*In German.*)
Using high speed cine photography of drop tests of parachutes a simple method was established from which could be obtained numerical details of velocity, retardation and force as a function of time. By integration of a non-linear differential equation involving the radius of the filling canopy and the flight path angle as empirical functions of time, results were obtained which agreed with experiment.—(5.3).

Über den zeitlichen Verlauf der Füllung bei Fallschirmmodellen verschiedener Bauart und Luftdurchlässigkeit. H-D Melzig. D.F.L. Bericht 129. 1960. (*In German.*)
Results are given of wind tunnel tests conducted on the time history of inflation, and the relation between free stream velocity and drag for textile parachute models of various shapes and permeability. The total force acting on the parachute was measured by strain gauges and the inflation was observed by a 16 mm. cine camera.—(5.3).

EXTRA-ATMOSPHERIC TECHNOLOGY

See also MATERIALS
MATHEMATICS

The aerodynamic drag of near earth satellites. G. E. Cook. C.P. 523. 1960.
The drag of a body in free molecule flow, the flow régime appropriate to a satellite in orbit, is discussed, and the molecular speed ratio is related to the properties of the upper atmosphere. The mechanism of molecular reflection at the satellite's surface and the surface temperature are considered. The drag coefficients of some simple shapes are quoted for appropriate molecular speed ratios, and the drag coefficients are obtained for cylinders and a cone with axes inclined at any angle to the direction of motion.—(8.2 × 1.2.3.1).

Perturbations in the motion of artificial satellites caused by the earth's oblateness. V. F. Proskurin and Yu. V. Batrakov. R.A.E. Lib. Trans. 927. *Dec.* 1960.
Literal expressions have been obtained for first order perturbations in elements of the orbits of artificial satellites with an accuracy up to the first order in the oblateness of the earth and the fifth order in eccentricity inclusive.—(8.2).

An exploratory study of thermoelectrostatic power generation for space flight applications. B. H. Beam. N.A.S.A. T.N. D-336. *Oct.* 1960.
A study has been made of a process in which a solar heating cycle is combined with an electrostatic cycle for generating electrical power for space vehicle applications. The power unit referred to as a thermoelectrostatic generator, is a thin film, solid dielectric capacitor alternately heated by solar radiation and cooled by radiant emission. The theory of operation to extract electrical power is presented and results of an experiment to illustrate the principle are described. Estimates of the performance of this type of device in space in the vicinity of earth are included. Values of specific power of several kilowatts per kilogram of generator weight are calculated for such a device employing polyethylene terephthalate dielectric.—(8.2 × 27.7 × 32.2.2).

The vector field proton magnetometer for I.G.Y. satellite ground stations. I. R. Shapiro et al. *N.A.S.A. T.N. D*-358. *Oct.* 1960.
The application of homogeneous-bias fields to a proton precessional magnetometer allows the measurement of the vector field by measuring the absolute scalar field F, declination variations ΔD, and inclination variations ΔI. A vector proton magnetometer that has been in operation at nine minitrack stations since the spring of 1958 is described.—(8.2 × 32.2 × 18.1).

The solar wind. J. R. Herring and A. L. Licht. N.A.S.A. T.N. D-487. *Sept.* 1960.
Parker's model of a spherically expanding corona is compared with D. E. Blackwell's observations of the 1954 minimum equatorial corona. A further discussion of the effects of the "solar wind" on the lunar atmosphere and surface is given.—(8.1).

Static longitudinal stability and control characteristics at a Mach number of 1·99 *of a lenticular-shaped reentry vehicle. C. M. Jackson and R. V. Harris. N.A.S.A. T.N. D*-514. *Oct.* 1960.
A model composed of a lenticular-shaped body with two fin configurations was tested at angles of attack from 0° to 90°.—(8.2 × 1.8.2.2 × 3.14).

Direct measurements of ion density and conductivity in the D-region. E. C. Whipple. N.A.S.A. T.N. D-567. Oct. 1960.
In principle, the electrical properties of the *D*-region can be measured by direct-measurement techniques now used in the lower atmosphere (below about 30 kilometres). The sounding rocket carries the instrumentation. An ion collector experiment adapted for rocket determination of ion density and conductivity in the *D*-region (up to about 80 kilometres) is described. Results obtained when this experimental collector was flown in the Viking-5 rocket are discussed; and the importance of dust in providing a recombination surface for ions and electrons is considered for two areas: the *D*-region and interplanetary space.—(8.1×24×32.2).

AVIATION MEDICINE

Physiological instrumentation of pilots for test and operational flights in navy high performance jet aircraft Phase I—Preliminary investigations. F. H. Austin. AGARD Report 240, *May* 1959.

ELECTRONICS

See also INSTRUMENTS AND EQUIPMENT

The motion of charged particles in a radiofrequency field. M. F. Romig. Convair Sc. Res. Lab. Res. Note 44. *Jan.* 1961.
The collision-free motion of charged particles is found for the case of an electrodeless ring discharge at breakdown. This radio-frequency field configuration consists of a spatially constant axial magnetic field and an azimuthal electric field which varies linearly with distance from the discharge tube axis. An analytic solution is obtained for the equations of motion.—(11×32.2.1).

High gain aerials. G. Callede. R.A.E. Lib. Trans. 924. *Nov.* 1960.
A study is made of high gain aerials suitable for the terrestrial end of earth-space communication systems. Expressions are given for the gain and beam-width of end-fire and aperture aerials; in particular, the circular parabolic reflector is examined. Mention is made of noise performance, and a table shows some examples of high-gain aerials which are in use for radio-astronomy and space communication.—(11).

FLIGHT TESTING

See also AERODYNAMICS—PERFORMANCE
STABILITY AND CONTROL

Some tests on an Avon-Canberra installation to measure thrust in flight. R. Hall et al. *C.P.* 518. 1960.
Three aerodynamic methods of thrust measurement have been investigated:— the "standard" single pitot method; the use of a jet pipe pitot pressure rake; and the use of a pitot-static pressure rake at the plane of the final nozzle. Further flight tests are required to investigate the scatter of experimental results which did occur and to obtain a more accurate assessment of the thrust performance of the engine at high altitudes.—(13.3×1.12.5×27.1.1.2).

Measurement of the maximum speed attained by the X-15 airplane powered with interim rocket engines. W. H. Stillwell and T. J. Larson. N.A.S.A. T.N. D-615. Sept. 1960.
On 4th August 1960 a flight was made with the X-15 aeroplane to achieve the maximum speed possible with two interim engines. The details of the techniques utilised to determine the maximum Mach number (3·31 ± 0·04) and speed (2,196 m.p.h. ± 35) attained are presented.—(13.3×1.7×3.6).

Methods of flight testing in the Soviet Union. H. G. Schumann. AGARD Report 234. *May* 1959.
Flight testing methods adopted in the Soviet Union are reviewed, based on data published in the Soviet Union during the last few years. Manoeuvrability and handling qualities are the subjects mainly discussed and a Table is included which summarises the flight tests required to provide the information necessary to determine the characteristics of a new design of aircraft.—(13.2×1.8).

FUELS AND LUBRICANTS

See also INSTRUMENTS AND EQUIPMENT

Lubricating properties of some bonded fluoride and oxide coatings for temperature to 1500°*F. H. E. Sliney. N.A.S.A. T.N. D-478. Oct.* 1960.
Solid-lubricant coatings, with good chemical stability in air to at least 1500°F, were formulated. Friction and wear data were obtained with hemispherical specimens sliding at 430 ft./min. against rotating discs coated with the experimental lubricants. The relative thermal stabilities of metal halides in air were estimated by thermochemical calculations and checked by X-ray diffraction.—(14.3×32.1).

Lubricant behaviour in concentrated contact. The effect of temperature. F. W. Smith. N.R.C. Report M.P.-17. *Aug.* 1960.
Experiments are described on the frictional behaviour of a petroleum oil in the contact zone between a steel roller and an aluminium one at 23°C and between steel rollers and between tungsten carbide rollers at 23°C, 100°C and 190°C.—(14.1).

HYDRODYNAMICS

See also AERODYNAMICS—BOUNDARY LAYER

Sur l'influence de l'accélération sur la résistance au mouvement dans les fluides. J. L. Luneau. Pubs. Sc. et Techs. 363 1960. (*In French.*)
The experimental study of the drag of uniformly accelerated bodies of simple geometrical shapes has confirmed the increase of drag as due to the inertia of the wake and indicates the influence of acceleration on changes in flow régime around the bodies. The drag and lift of a model of a wing in uniformly accelerated motion undergoes important modifications.—(17.1).

INSTRUMENTS AND EQUIPMENT

See also EXTRA-ATMOSPHERIC TECHNOLOGY

A photo-electric device for the measurement of quantity of liquid. R. Sandri. N.R.C. Report M.I.-822. *Sept.* 1960.
A photo-electric device producing an output voltage which is a linear function of the quantity of liquid contained in the measuring tube is described. A detailed description is given of the optical system, its function and possible sources of error. The method of calibration of the system is described. The apparatus can follow rapid changes of quantity of liquid.—(18.1×32.2.4).

Development of instrumentation for a hypervelocity range. P. L. Clemens and M. K. Kingery. A.E.D.C.-T.N.-60-230. *Dec.* 1960.
Recent progress in the development of optical and radio-telemetry instrumentation for a hypervelocity range is discussed.—(18.1×11×32.2.4×25.2).

Über pneumatisch-elektronische Verfahren zur Messung des Krafts-offvorrats. 1. *Teil-Pneumatik. E. Nickel. D.F.L. Bericht* 109. 1960. (*In German.*)—(18.2×14.1).

MATERIALS

See also MECHANICAL ENGINEERING

Mechanical properties of solid and porous stainless steel sheet material at elevated temperatures. J. B. Lord. C.o.A. Note 107. *Oct.* 1960.
A series of tensile tests in the temperature range from 20°C to 1000°C were carried out on three stainless steel sheets materials, namely D.T.D. 166B, D.T.D. 171 and a woven porous material called Rigimesh. Values of Young's modulus, secant modulus, proof stress and ultimate stress were determined over the whole temperature range, values of Poisson's ratio were determined at temperatures up to 500°C. Room temperature tests were also carried out on the woven material at various orientations of the weave.—(21.2.1).

Materials for astronautic vehicles. A. J. Murphy. C.o.A. Report 139. *Nov.* 1960.
The nature of the environment in outer space and its significance for materials of construction of astronautic vehicles are considered.—(21.2×21.3×8.2).

Glass-resin interactions in laminates revealed by alternating bending fatigue tests. A. Kh. Iablokoff. R.A.E. Lib Trans. 923. *Oct.* 1960.
As the laminates are heterogeneous materials, the neutral fibre is not on the axis of the sample, and moves for each alternation. It follows that the shearing gradient also varies for each cycle. These conditions allow part of the glass-resin inter-

face to be defined, and the optimum elastic characteristics of resins to be used for high temperature laminates to be stated.—(21.3.3×31.2.2.9.2.1.1).

Investigation of problems associated with the use of alloyed molybdenum sheet in structures at elevated temperatures. E. E. Mathauser et al. *N.A.S.A. T.N. D*-447. *Oct.* 1960.
Results of an experimental study to explore the capabilities and limitations of thin Mo—0·5Ti molybdenum-alloy sheet for structural applications at high temperatures are presented.—(21.2.2×21.2.3×21.6).

Characteristics of a 60-inch arc-image furnace and application to the study of materials. R. W. Peters et al. *N.A.S.A. T.N. D*-505. *Oct.* 1960.
A double paraboloidal-type carbon arc image furnace has been developed for the evaluation of engineering materials at high temperatures and under high thermal flux conditions.—(21.6.2).

Practical implications of trace additions of silver to commercial aluminium-zinc-magnesium alloys. I. J. Polmear. A.R.L. Report M.E.T. 39. *Sept.* 1960.
Earlier work revealed that small amounts of silver may have a marked effect on the structure and age hardening characteristics of certain high purity Al-Zn-Mg alloys. A study has now been made of the effects of adding silver to several commercial Al-Zn-Mg alloys, notably D.T.D. 683.—(21.2.2).

The effects of "as forged" surfaces and notches on the fatigue strength of S.A.E. 4140 *steel* (*U.T.S.* 140,000 *P.S.I.*). *J. Y. Mann. A.R.L. Note S.M.* 256. *Sept.* 1959.
Rotating cantilever fatigue tests have been carried out on S.A.E. 4140 steel specimens (U.T.S. 140,000 p.s.i.) with "as forged" surfaces and with vee-notches of $Kt=4$.—(21.2.1×31.2.2.2.2).

Pratique du sandwich nid d'abeilles alliage leger. C. Thomas. AGARD Report 217. *Oct.* 1958. (*In French.*)
After a review of current methods of manufacture, the following points in the use of sandwich construction are discussed:—safety in service and ways of achieving this; fatigue problems and the "fail-safe" concept; sampling of structures, taking into account the stresses to which the honeycomb is subjected; future prospects for sandwich construction in relation to kinetic heating problems.—(21.2.3).

Influence a la température ambiante des éléments constitutifs sur les propriétés méchaniques des stratifiés. A. Kh. Iablokoff. O.N.E.R.A. N.T. 62. 1960. (*In French*).—(21.3.3).

MATHEMATICS

See also AERODYNAMICS—BOUNDARY LAYER
MISSILES

Relatavistic rocket mechanics. H. G. L. Krause. N.A.S.A. T.T. F-36. *Oct.* 1960.
The mechanics of the Special Theory of Relativity are extended to systems having a rest mass changing in time (rockets). The principles of momentum and energy are investigated as well as the law of the decrease of mass of an arbitrarily accelerated rocket in free space without external forces, and in fact, in the system of the stationary observer on earth and in the system of the astronaut moving with the rocket. Two special cases are treated; the motion of a rocket with constant self-acceleration and the motion of a rocket with constant thrust.—(22.3×32.2×8.2×27.3).

Conducting sheet analogues for the solution of potential problems. C. J. Rallis et al. *Univ. Witwatersrand. Rep.* 1/60. *Oct.* 1960.
Teledeltos recording paper was found to be the material most suitable for the solution of potential problems. When applying boundary conditions with colloidal graphite, errors in problems ranging from "Shape Factor" determinations to fields having varying two-dimensional boundary potentials were found to be between 5 and 2 per cent. A simulation of abrupt charges in conductivity was achieved, and the effects of anisotropy and humidity assessed.—(22.1×34.3.3×1.4.1×32.2.1).

Analog techniques for measuring the frequency response of linear physical systems excited by frequency-sweep inputs. W. H. Reed et al. *N.A.S.A. T.N. D*-508. *Oct.* 1960.
Some data-reduction methods using general-purpose analog computing equipment and compatible testing techniques for determining the frequency response of linear physical systems are examined.—(22.2×2×33.1.2).

MECHANICAL ENGINEERING

A study of some factors affecting rolling-contact fatigue life. T. L. Carter. N.A.S.A. T.R. R-60. 1960.
The rolling-contact fatigue spin rig was used to evaluate the effect on rolling-contact fatigue life of the following factors: stress, forging fibre orientation, lubricant viscosity, lubricant base stock, temperature, dry-powder lubricants, metallurgical structure, and alloy composition.—(23.1×27×21×31.2.2.1).

The magnetic field of a finite solenoid. E. E. Callaghan and S. H. Maslen. N.A.S.A. T.N. D-465. *Oct.* 1960.
The axial and radial fields at any point inside or outside a finite solenoid are derived in terms of tabulated elliptic junctions. Dimensionless field plots are presented for a wide range of solenoid lengths.—(32.2.1).

MISSILES

See also INSTRUMENTS AND EQUIPMENT

Effects of fineness ratio and Reynolds number on the low-speed crosswind drag characteristics of circular and modified-square cylinders. L. W. McKinney. N.A.S.A. T.N. D-540. *Oct.* 1960.
A wind tunnel investigation was made at several fineness ratios between 2 and 14 for a range of Reynolds numbers from approximately 300,000 to 1,650,000 which corresponded to Mach numbers from 0·057 to 0·377. Effects of hemispherical ends on the drag characteristics of some of the circular cylinders were also obtained.—(25.1).

Drag and stability derivatives of missile components according to the modified Newtonian theory. J. Don Gray. A.E.D.C.-T.N.-60-191. *Nov.* 1960.
The modified Newtonian approximation for the pressure distribution on bodies in hypersonic flow has been used to derive expressions for the zero-lift drag and the initial slopes of the normal-force and pitching-moment curves. A set of working graphs are presented for blunted cones, truncated cones, spherical segments, and rounded-shoulder cylinders. From these graphs and the appropriate equations the drag and static-stability derivatives of composite missile configurations may be readily estimated.—(25.2×1.2.3.1×1.8.0.1).

Les effets secondaires de jet d'un engin autopropulsé. P. Girardin et F. Tesson. Pubs. Sc. et Tech. 373. 1960.
A kinematic relation exists which may be used as a basis for (*a*) a simplified theory which shows the existence, in addition to the main propulsive effect of the jet, of a secondary tensor consisting mainly of a force normal to the axis acting midway between the centre of gravity and the exit plane; this force has a damping effect. Ramjets are also treated: (*b*) a general theory covering a broad hypothesis is contemplated allowing for variations in shape with respect to time. An analysis of other authors' works is also given.—(25×27.3×27.4×22.2).

METEOROLOGY *see* EXTRA-ATMOSPHERIC TECHNOLOGY

PROPELLERS *see* AIRCRAFT

PRODUCTION ENGINEERING *see* AIRCRAFT OPERATION

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EXTRA-ATMOSPHERIC TECHNOLOGY
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SCIENCE GENERAL *see* EXTRA-ATMOSPHERIC TECHNOLOGY
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